Center for Research on Sustainable Forests

crsf.umaine.edu

2020 Annual Report

Aaron Weiskittel
Meg Fergusson

THE UNIVERSITY OF MAINE

The Center for Research on Sustainable Forests (CRSF) was founded in 2006 to build on a rich history of leading forest research and to enhance our understanding of Maine's forest resources in an increasingly complex world. The CRSF houses a variety of forest research programs and initiatives, including the Cooperative Forestry Research Unit (CFRU), Northeastern States Research Cooperative (NSRC), Forest Climate Change Initiative (FCCI), Intelligent GeoSolutions (IGS), Nature-based Tourism, and the National Science Foundation Center for Advanced Forestry Systems (CAFS). The CRSF continues to develop, integrate, and apply emerging technologies and informatics methods to address current and future issues to support the sustainable management of the region's natural resources.

Our mission is *to conduct and promote leading interdisciplinary research on issues affecting the management and sustainability of northern forest ecosystems and Maine's forest-based economy.*

Citation: Fergusson, M. & Weiskittel, A. (Ed.). 2020. Center for Research on Sustainable Forests 2020 Annual Report. University of Maine. Orono, ME. 90 p.

Center for Research on Sustainable Forests
University of Maine
5755 Nutting Hall
Orono, Maine 04469-5755
crsf.umaine.edu

Cover photo by M. Fergusson. Used with Permission.

Highlights

- In FY20, CRSF researchers brought in 13 awards worth $4,303,096. This is an increase of nearly $3.75M from FY19.
- CRSF researchers submitted 20 proposals in FY20 that, if awarded, could bring in more than $5M in extramural funding.
- A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The $202,058 investment from MEIF leveraged $546,944 from other CRSF sources and $4,303,096 in extramural grants for a total leverage of $4,850,040 of additional research funding—a $24.00 return on investment for every dollar of MEIF funding.
- PI Weiskittel awarded $500K from NSF for a 5-year Phase 3 of I/UCRC CAFS program that links UMaine to 6 other universities across the country and is led by CRSF.
- CRSF Director Weiskittel received the 2019 Maine Forest Products Council's Presidential Award for his dedication and service to the state's forest industry.
- The $3 million INSPIRES NSF EPSCoR Track 2 project started Aug 1, 2019 and is an interjurisdictional partnership between Maine, New Hampshire, and Vermont.
- INSPIRES-affiliated UMaine researchers include 20 faculty (9 early career), 1 post-doc, 3 professional staff, and 4 students (2 graduate level).
- With UVM, UNH, and SUNY-ESF, CRSF successfully relaunched the Northeastern States Research Cooperative (NSRC) with $1.6M in available for research funding.
- IGS released the web-based, interactive decision-support tool, Maine Forest Ecosystem Status and Trends (ForEST) App.
- IGS established a collaboration with the Maine GeoLibrary, NOAA Coastal Change Analysis Program, and University of Maine Wheatland Geospatial Lab to fund and develop a next-generation, high-resolution land cover map of Maine, including detailed forest type information at 10 m spatial resolution.
- FCCI co-hosted a Science & Practice forum for nearly 60 stakeholders from across Maine to catalyze scientist-manager discussions about current research and stakeholder needs, grow Maine’s forest climate adaptation community of practice, and provide useful information for the work of the Maine Climate Council.

Highlights

- FCCCI's Aaron Weiskittel, Ivan Fernandez, and Adam Daigneault were nominated to serve on Maine Climate Council's Scientific and Technical Subcommittee and its Natural and Working Lands Working Group.
- Maine's Carbon Budget (ver.1) fact sheet released by FCCI: https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/
- Holt Research Forest collaboration with Maine Medical Center Insect Borne Disease Lab to better understand the small mammal/black-legged tick/disease mechanism.
- Maine Forestry Industry Sub-Sector Analysis team developed a novel Vulnerability Assessment Model of climate change impacts that integrates biophysical and socio-economic data.
- Draft report on the greenhouse gas mitigation potential of natural climate solutions released in April.
- Four undergraduate students and four graduate students on the Fostering Coastal Community Resilience in Maine project conducted social science research and spatial analysis.
- A new CRSF project on resilience indicators for ensuring equitable, continued investment in Northern Border communities launched in January.
- The CFRU engaged thirty-three members representing 8.15 million acres of Maine's forestland this year. CFRU members contributed $541,465 to support research activities during Fiscal Year 2019-20.
- Nearly 40 members attended the 2019 fall field tour visiting four sites in Kibby Township on Weyerhaeuser forestland. Topics and sight visits covered the latest CFRU research at the interface of forestry and wildlife habitat.
- CAFS funding supported two projects led by University of Maine researchers (Understanding and Modeling Competition Effects on Tree Growth and Stand Development across Varying Forest Types and Management Intensities and Modeling the Influence of Spruce Budworm on Forest Productivity).
- Output for CRSF researchers include 14 journal articles, 45+ presentations, 6 research reports, 14 media-related publications, 8 theses, and 2 data tools/publications.

Contents

Director's Report

FY20 saw exciting changes in CRSF with several new initiatives launched, while progress continues on many other ongoing efforts. In particular, FY20 saw the start of two National Science Foundation funded and CRSF-led research projects. The first is the INSPIRES project, a multi-year research collaboration between Maine, New Hampshire, and Vermont focused on harnessing Big Data to better understand and forecast the region's forest given current as well as future uncertainties.

The other effort was a successful Phase 3 reboot of the National Science Foundation Industry-University Collaborative Research Center, Center for Advanced Forestry System (CAFS), for which I have served as Director since 2016. CAFS provides direct connections among several additional universities across the United States, including North Carolina State University, Oregon State University, Purdue University, University of Georgia, University of Idaho, and University of Washington, as well as to forest industry partners. Phase 3 of CAFS will be a five-year effort and, I hope, will lead to the successful graduation of the IUCRC.

As highlighted by this report, continued initiatives within CRSF include the Cooperative Forestry Research Unit (CFRU), Forest Climate Change Initiative (FCCI), Intelligent GeoSolutions (IGS) Initiative, Nature-Based Tourism, and North-eastern States Research Cooperative (NSRC). Several key outcomes from these various efforts over the past FY include continued expansion of CFRU's Maine Adaptive Silviculture Network (MASN), an interactive forum that brought together over 60 scientists and practitioners to discuss the potential impacts of climate change in Maine, the further refinement of the ForEST web-based mapping application, and the formation of NSRC's first External Advisory Committee to help guide future research efforts.

Going forward, a key priority for CRSF will be effectively communicating the research to a broader audience. We have continued to revamp our online presence by updating, expanding, and revising our websites, the addition of various social media platforms, and targeted marketing campaigns. Our CRSF websites did see stable usage over the last FY when compared to the prior FY, which will be an important metric we will continue to track as we go forward to assess our effectiveness.

FY20 saw the departure of CFRU Program Leader Brian Roth, who was an integral part of CRSF and worked closely with many stakeholders throughout the region over the years. Brian helped launch MASN, worked closely with our Canadian counterparts on spruce budworm, and kept the CFRU membership well served. His enthusiasm, dedication to the profession, and tireless effort will be missed.

I remain excited about where CRSF has been and is currently headed. My thanks to the many scientists, students, staff, and partners who make what we do possible and so rewarding. We look forward to another productive FY ahead.

Dr. Aaron Weiskittel
Director, Center for Research on Sustainable Forests and
Center for Advanced Forestry Systems
Irving Chair of Forest Ecosystem Management
Professor of Forest Biometrics & Modeling
Co-Director, Northeastern States Research Cooperative

CRSF Essentials

People

Staff

Aaron Weiskittel, CRSF Director

Meg Fergusson, CRSF Communications & Outreach Specialist

Leslee Canty-Noyes, CRSF/CFRU Administrative Specialist

John Lee, Research Associate, Howland Research Forest

Holly Hughes, Research Associate, Howland Research Forest

Jack Witham, Associate Scientist, Holt Forest

UMaine Affiliated Faculty and Staff

Adam Daigneault, Assistant Professor (CRSF, FCCI)

Alessio Mortelliti, Associate Professor (CFRU)

Ali Abedi, Professor (INSPIRES)

Amanda Klemmer, Assistant Research Professor (CFRU)

Amber Roth, Assistant Professor (CFRU)

Anil Raj Kizha, Assistant Professor (CFRU)

Anthony Guay, Remote Sensing Technical Specialist (CRSF, CFRU)

Bruce Segee, Professor (INSPIRES)

Cheryl Spencer, Scientific Research Specialist (NSRC)

Chris Wilson, Programming Specialist (IGS)

Dan Harrison, Professor (CFRU)

Daniel Hayes, Associate Professor (FCCI. CFRU)

Darren Ranco, Professor (INSPIRES)

Erin Simons-Legaard, Assistant Research Professor (CRSF, IGS, CFRU)

Franzi Peterson, Assistant Professor (INSPIRES)

Hamish Grieg, Associate Professor (CFRU)

Holly Hughes, Research Associate (Howland)

Ivan Fernandez, Professor (FCCI, NSRC)

Jack Witham, Research Scientist (Holt)

Jane Haskell, George J. Mitchell Center for Sustainability Solutions, Univ. of Maine (Tourism)

Jay Wason, Assistant Professor (FCCI)

Jing Yuan, Post-Doc (INSPIRES)

John Lee, Research Associate (Howland)

Josh Puhlick, Research Associate (CRSF, CFRU)

Kasey Legaard, Associate Scientist (CRSF, IGS)

Kate Beard-Tisdale, Professor (INSPIRES)

Keith Kanoti, Manager, University Forests (CFRU)

Larry Whitsel, Research Scientist (INSPIRES)

Laura Kenefic, Research Forester/Faculty Associate (NSRC, CFRU, PEF)

Laura Millay, Research and Evaluation Coordinator (INSPIRES)

Leo Edmiston-Cyr, Scientific & Technical Programmer(CRSF)

Marina Van der Eb, Maine STEM Partnership Coordinator (INSPIRES)

Neil Thompson, Assistant Professor, UMFK (CFRU)

Nicole Rogers, Assistant Professor, UMFK (CFRU)

Parinaz Rahimzadeh-Bajgiran, Assistant Professor (CFRU)

Salimeh Yasaei Sekeh, Assistant Professor (INSPIRES)

Sam Roy, Research Assistant Professor (INSPIRES)

Sandra De Urioste-Stone, Associate Professor (Tourism, FCCI)

Sara Lindsay, Assistant Professor (INSPIRES)

Shawn Fraver, Associate Professor (Howland, FCCI)

Silvia Nittel, Associate Professor (INSPIRES)

Susan McKay, Professor (INSPIRES)

Torsten Hahmann, Assistant Professor (INSPIRES)

Researchers from Partner Institutions

Adrienne Leppold, Maine Dept. of Inland Fisheries & Wildlife (CFRU)

C.T. (Tat) Smith, University of Toronto (CFRU)

Chris Hennigar, University of New Brunswick (CFRU)

Chris Woodall, US Forest Service (NSRC)

Clarke Cooper, Scientific Researcher/Data Manager (Holt)

Daniel Kneeshaw , University of Montreal

Dave Hollinger, US Forest Service (Howland)

David MacLean, University of New Brunswick (CFRU)

Inge Stupak, University of Copenhagen (CFRU)

Marie-Cecile Gruselle, Research faculty (NSRC)

Nicholas Fisichelli, President and CEO, Schoodic Institute (FCCI)

Peter Nelson, Forest Ecology Director, Schoodic Institute (INSPIRES)

Student Researchers

Graduate Students

Alex George (PhD, Forest Resources)

Bryn Evans (PhD, Wildlife)

Cen Chen (PhD)

Erin Fien (MSc, Forest Resources)

Gabriela Franzoi Dri (PhD, Conservation Biology)

Gabrielle Sherman (PhD, Forest Resources)

Harikrishnan Soman (MSc, Forest Resources)

Henry Amponsah (MF)

Jeanette Allogio (MSc, Forest Resources)

Jennifer Carroll (PhD)

Kaitlyn Wilson (MSc Wildlife Ecology)

Kirstin Fagan (Ph.D., WLE)

Libin T Louis (PhD, Forest Resources)

Samantha Anderson (MF, Forest Resources)

Sonia Naderi (PhD, Elec. & Computer Engineering)

Tyler Woollard (MSc, WLE)

Valeria Briones (MSc, Forest Resources)

Varun Anand (MF, Forest Resources)

Undergraduate Students
(UMaine unless otherwise noted)

Autumn Brann (Forest Resources)

Danielle Wyman (EES)

David Holmberg (Wildlife Ecology)

Emily Roth (Forest Resources)

Emily Tomak (EES)

Emma Payne (Cornell University)

Evan Nahor (Forest Resources)

Hateya Levesque (Forest Resources)

Jack Ferrara (EES)

Jack Ferrara (Forest Resources)

Jack Prior (McGill, computer programming)

Jacob Burgess (PRT)

Jasmine Gregory (EES)

Jordan Goodstein (Forest Resources)

Joseph Reed (Economics)

Josh Gibson (PRT)

Joshua Goldsmith (Forest Resources)

Joshua Goldsmith (Forest Resources)

Lauren Keefe (Forest Resources)

Meredith Melendy (EES)

Michaela Kuhn (PRT)

Mike Turso (Wildlife Biology)

Nathaniel Harris (EES)

Noah Coogen (Fores Resources)

Paige Howell (EES)

Robert Hart (EES)

Skye Cahoon (Zoology)

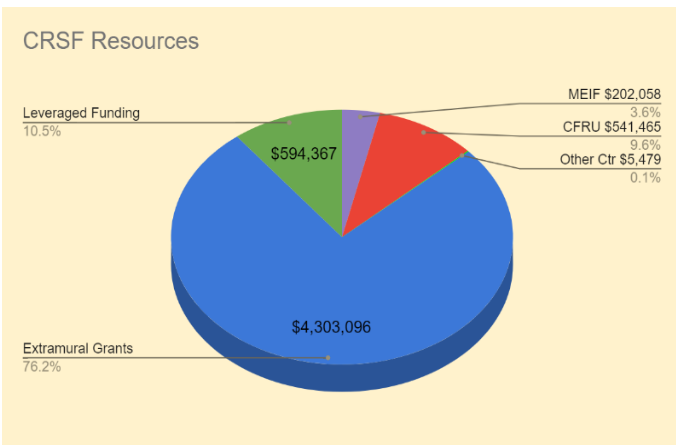
Thayer Whitney (Elec. & Computer Engineering)

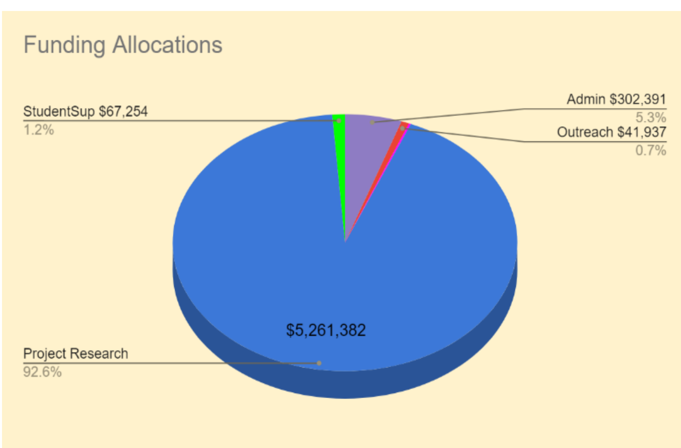
Victoria Nicholas (Elec. & Computer Engineering)

Financial Report

During FY20 (July 1, 2019-June 30, 2020), CRSF researchers were awarded $4,303,096 to support their research, an increase of nearly $3.75M from FY19. An additional 20 proposals were submitted during FY20 which, if awarded, could bring in more than $5M in extramural funding. These awards came from the National Science Foundation, US Department of Agriculture, Nature Conservancy, and Maine TREE Foundation.

Income supporting the center in FY20 came from programs administered by or that support CRSF/CFRU staff and general operations, student employees, and outreach efforts, along with extramural grants received by CRSF scientists from outside agencies that support specific research projects described in this report. CFRU cooperators contributed $541,465 to support applied forestry research lead primarily by University of Maine System faculty. Total funding of the CRSF for FY20 was nearly $5.1 million (see Table 1 for budget detail). CRSF scientists were able to leverage their grant awards for an additional $594,367 in funding (Table 2). The majority (92.6%) of the CRSF budget is allocated directly to the research projects described in this report, supporting CRSF projects and initiatives under the CFRU, Howland and Holt Research Forests, INSPIRES NSF research, Northeastern States Research Cooperative, Penobscot Experimental Forests, Forest Climate Change Initiative, Nature-based Tourism, Intelligent GeoSolutions, and the CAFS NSF Industry/University Cooperative. The remaining funds support personnel salaries and operating costs, outreach (including webinars and meeting support), and student employees and tuition aid.





A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The $202,058 investment from MEIF helps to cover Director Weiskittel's salary and fringe as well as the Center's personnel and operating costs. MEIF funds helped to leverage $594,367 from other CRSF sources and $4,303,096 in extramural grants for a total leverage of $4,850,040 of additional research funding—a $24.00 return on investment for every dollar of MEIF funding.

Table 1. CRSF Project Awards and MEIF Return on Investment

Center Sources	PI	Source	Amount		
Maine Economic Improvement Fund	Weiskittel	MEIF	**$202,058**		
UMaine Munsungan Fund	Weiiskittel	Gift	$4,578		
CRSF Gift Fund	Weiskittel	Gift	$901		
Cooperative Forestry Research Unit	Weiskittel	CFRU	$541,465		
		Center Total	**$749,002**		
Extramural Project Grants					
Source	***PI***	***Project***	***Sponsor***	***UMaine***	***Project Total***
USDA	Weiskittel	National FIA Biomass Project Maine	$40,000	$18,220	$58,220
National Council of Air and Stream Quality	Weiskittel	Projecting carbon sequestration on the Maine Adaptive Silviculture Network	$10,000	$2,022	$12,022
University of Vermont / US Dept of Agriculture	Weiskittel	Northeastern States Research Cooperative 2.0	$59,000	$9,365	$68,365
USDA	Simons-Legaard Weiskittel Legaard	Fostering forest landscape planning and adaptive capacity in anticipation of a regional insect outbreak	$487,717	$2,883	$490,600
USDA	Daigneault Weiskittel	A Resilience Indicators Approach to Ensuring Equitable, Objective and Continued Investment in Northern Border Communities	$105,030	$63,678	$168,708
Maine Tree Foundation	Jack Witham	Holt Research Forest - 2020	$67,354	$30,799	$98,153
USDA	Fraver	AmeriFlux work at the Howland Research Forest, Maine	$194,782	$89,599	$284,381
National Science Foundation	Weiskittel	I/UCRC Phase III: Center for Advanced Forestry Systems	$100,000	$18,531	$118,531
American Forests / US Climate Alliance / Doris Duke Charitable Foundation	Daigneault Weiskittel Fernandez	An Integrated Approach to Quantifying the GHG Mitigation Potential of Natural Climate Solutions from Maine's Working Lands	$132,174	$40,124	$172,298
Nature Conservancy	Puhlick Weiskittel	Ecological Reserves Carbon Analysis	$27,135	$2,878	$30,013
National Science Foundation	Weiskittel	RII Track 2 FEC: Leveraging informatics to resolve uncertainties in the Northern Forest's carbon budget	$3,000,000	$0	$3,000,000
USDA	Weiskittel	Sustaining Productive Forests in an Uncertain Future	$49,998	$27,414	$77,412
USDA	Weiskittel	Sustaining Productive Forests in an Uncertain Future	$29,906	$20,196	$50,102
		External Awards Total	**$4,303,096**	$325,709	$4,628,805
		Total	**$5,052,098**		
		CRSF Leveraged Funding	**$594,367**		
		TOTAL RESOURCES	**$5,646,465**		
		CRSF ROI	**$24.00**		

Table 2. Leveraged Funding

Source	Leveraged Funds	Related Project
Cooperative Forestry Research Unit	$8,500	Puhlick, Gruselle, Fernandez, & Roth. Soil productivity, carbon storage, and conservation on the MASN
Maine Farmland Trust	$25,000	Daigneault et al. Ag practices and farmer focus groups
Mitchell Center Sustainability Grant	$22,981	Daigneault et al. Practices related to soil health and mitigation
CFRU and CUGR (UMaine)	$3,100	Puhlick & Fernandez, relative risk of soil nutrient depletions among different intensities of tree biomass removal during timber harvesting in Maine, USA
Maine Outdoor Heritage Fund	$13,018	Holt Research Forest: Hire undergraduate students to complete inventory of trees
Center for Advanced Forestry Systems	$106,406	IGS: For multi-regional evaluation of new machine learning algorithms for mapping tree species distribution and abundance
MAFES (3 weeks for PI)	$4,664	Roth/Rusty Blackbird (CFRU)
UMaine Graduate Research Reinvestment Fund	$19,009	Roth/Rusty Blackbird (CFRU)
UMaine Grad School (TA to Douglas)	$1,758	Roth/Rusty Blackbird (CFRU)
UMaine Undergraduate Research Reinvestment Fund (to Levesque)	$7,000	Roth/Rusty Blackbird (CFRU)
William P. Wharton Trust	$14,709	Roth/Rusty Blackbird (CFRU)
UMaine CUGR (to Tomak, undergrad)	$3,100	Roth/Rusty Blackbird (CFRU)
Maine Outdoor Heritage Fund	$3,798	Roth/Rusty Blackbird (CFRU)
New Hampshire Audubon	$30,000	Roth/Rusty Blackbird (CFRU)
Private in-kind support	$20,000	Roth/Rusty Blackbird (CFRU)
MAFES (#ME041909)	$30,000	Kizha/Timber Harvesting on Soils (CFRU)
2018 USDA/ARS	$97,000	Kizha/Timber Harvesting on Soils (CFRU)
Grad School Government	$475	Mortelliti/Carnivores in Maine (CFRU)
US Department of the Navy	$16,405	Roth&Wilson/Bicknell's Thrush (CFRU)
MAFES (3 weeks for PI)	$4,664	Roth&Wilson/Bicknell's Thrush (CFRU)
UMaine Graduate School	$5,199	Roth&Wilson/Bicknell's Thrush (CFRU)
UMaine Foundation crowdfunding campaign	$785	Roth&Wilson/Bicknell's Thrush (CFRU)
CUGR (to M.Turso, undergrad)	$3,100	Roth&Wilson/Bicknell's Thrush (CFRU)
Seven Islands Land Company	$30,867	Hayes/Airborne LiDAR (CFRU)
UMaine VPR RRF	$31,132	Hayes/Airborne LiDAR (CFRU)
Maine Timberlands Charitable Trust	$10,967	Hayes/Airborne LiDAR (CFRU)
UMaine (various sources)	$26,720	Harrison/Marten populations (CFRU)
MAFES (USDA NIFA, McIntire-Stennis)	$31,200	Harrison/Marten populations (CFRU)
CAFS	$22,810	Puhlick/Hardwood mortality & growth response (CFRU)
TOTAL	**$594,367**	

Stakeholders

CRSF researchers strive to conduct not just cutting-edge forest science, but also real-world, applied science about Maine's forests, forest-based economy, and the public that supports them. We build and foster relationships with a wide variety of organizations and their people to achieve common goals. Over the past year we have worked with the following partners:

INTELLIGENT GEOSOLUTIONS

US Forest Service, Forest Inventory and Analysis Program
NOAA Coastal Change Analysis Program
Maine GeoLibrary
University of Maine Advanced Computing Group
University of Maine Barbara Wheatland Geospatial Analysis Laboratory

INSPIRES

Appalachian Mountain Club
US Forest Service, Northern Research Station
The Nature Conservancy
Dartmouth University
Maine Municipal Association
Wabanaki Youth Science Programs
University of New Hampshire
University of Vermont

COOPERATIVE FORESTRY RESEARCH UNIT MEMBERS

Irving Woodlands, LLC
Wagner Forest Management
BBC Land, LLC
Weyerhaeuser Company
Prentiss and Carlisle Company, Inc.
Seven Islands Land Company
Clayton Lake Woodlands Holding, LLC
Maine Bureau of Parks and Lands
Katahdin Forest Management, LLC
The Nature Conservancy
Fallen Timber, LLC
Baskahegan Company
Sylvan
Timberlands, LLC
Sandy Gray Forest, LLC
North Woods Maine, LLC
The Forestland Group, LLC
Appalachian Mountain Club
Frontier Forest, LLC
Downeast Lakes Land Trust
EMC Holdings, LLC
Baxter State Park, SFMA
Robbins Lumber Company
Solifor Timberland, Inc.

Mosquito, LLC
New England Forestry Foundation
American Forest Management
Sappi North America
LandVest
Huber Engineered Woods, LLC
Forest Society of Maine
David B. Field
Acadia Forestry, LLC

Howland Research Forest / Holt Research Forest / Penobscot Experimental Forest

Northern Arizona University, Flagstaff, AZ
Woods Hole Research Center, MA
NASA Goddard Space Flight Center, MD
University of Maryland, MD
Northeast Wilderness Trust, Montpelier, VT
Forest Ecosystem Monitoring Cooperative
USFS and Maine Forest Service

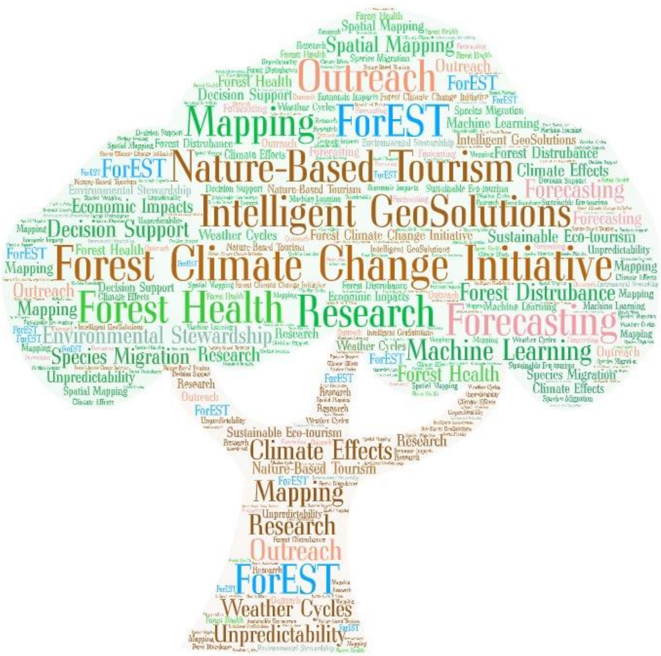
Daigneault/Resilience Indicators & GHG Mitigation Potential

US Forest Service
University of Vermont
Hubbard Brook Research Foundation
Northern Borders Regional Commission
USDA Climate Hub
Northern Institute of Applied Climate Science
The Nature Conservancy, Maine & Massachusetts
Maine Farmland Trust
Maine Climate Table
American Farmland Trust
Wolfe's Neck Center for Agriculture and the Environment
Clark University
Colorado State University

Puhlick/Forest Management Practices on Soil Productivity, Carbon Storage, & Conservation

Irving Woodlands, LLC
Seven Islands Land Company
LandVest Timberland Division
Wagner Forest Management
Huber Resources Corporation
Cooperative Forestry Research Unit
University Forests Office
Maine SFI Implementation Committee
Northeastern Soil Monitoring Cooperative
University of Toronto
USDA Natural Resources Conservation Service

CRSF Initiatives



The CRSF continued to strengthen and expand a number of initiatives in 2019-20.

The **Forest Climate Change Initiative (FCCI)** actively focused on carbon and climate outreach and community engagement through a well-attended public forum and the release of a number of carbon sequestration fact sheets. For FY21, considerable effort is being planned to develop FAQs and resources related to the forest carbon sequestration and natural resource solutions to decrease greenhouse gases.

The **Intelligent GeoSolutions (IGS)** team launched the web-based, interactive decision-support tool, Maine Forest Ecosystem Status and Trends (ForEST) App, designed to provide decision support to private and public forest managers, natural resource agencies, conservation organizations, and other stakeholders throughout an impending spruce budworm outbreak, using IGS layers and data collected by budworm monitoring programs. The ForEST App is publicly accessible at https://forestapp.acg.maine.edu. Looking forward to FY21, the IGS team will collaborate with members of NOAA and the Wheatland Lab at UMaine to develop a high-resolution statewide land cover dataset that documents ecosystem features on the earth's surface (e.g., trees, wetlands, etc.) and will serve as a foundational dataset to address a wide range of management issues.

Dr. Sandra De Urioste-Stone, who leads our **Nature-Based Tourism program**, continues to spearhead research into the impacts of climate change on land cover management. Students and researchers in the program are integrating geo-spatial, economic, and social science analyses to develop solution-driven approaches to climate change.

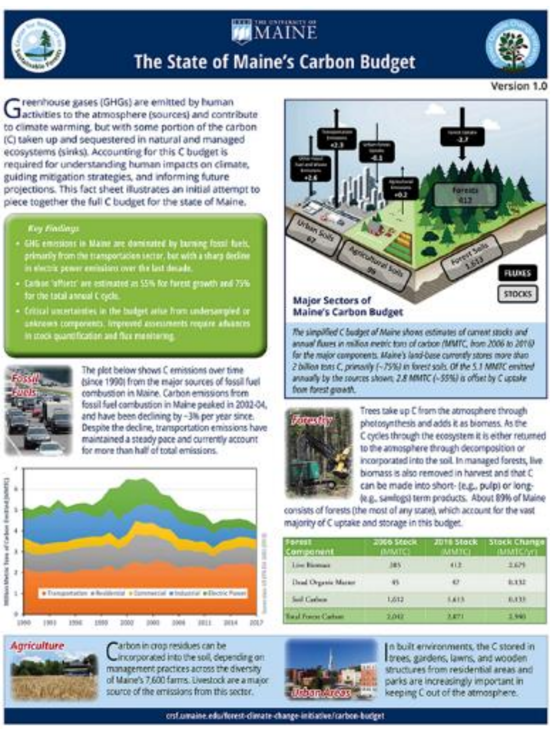
The CRSF is lucky to have ongoing support from our Munsungan and CRSF gift funds. These accounts support outreach and communication efforts and enable us to interact effectively with partners and stakeholders in the state and region. In February, the Munsungan Endowment made it possible for CRSF to host the FCCI Science and Practice Forum on forest climate change and adaptation. Gifts to the CRSF fund benefit student researchers and special projects on forest-related issues.

Forest Climate Change Initiative

crsf.umaine.edu/forest-climate-change-initiative

The FCCI team is a collaboration of interdisciplinary scientists from the University's School of Forest Resources, School of Food & Agriculture, and the Climate Change Institute, Schoodic Institute at Acadia National Park, and the Appalachian Mountain Club.

FCCI released the first version of its State of Maine Carbon Budget Fact Sheet (Figure 1; https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget) in January 2020. The estimate, by major emissions source and land use category, is the collaborative outcome of faculty, graduate students, and state scientists to compile, synthesize, and analyze Maine's carbon budget between 2006-2016. Key findings from the assessment include the importance of Maine's forests and their associated wood products, that may currently offset approximately 75% of the state's annual fossil fuel carbon emissions, and that the highest carbon stock densities were estimated to be in the state's wetlands and salt marshes. This analysis is one of the first estimates of this kind for the state and helps frame the discussion around Maine's carbon cycle. Going forward, the group is seeking funding that would allow for more significant analysis and expanded monitoring.


THE UNIVERSITY OF MAINE

The State of Maine's Carbon Budget

Version 1.0

Greenhouse gases (GHGs) are emitted by human activities to the atmosphere (sources) and contribute to climate warming, but with some portion of the carbon (C) taken up and sequestered in natural and managed ecosystems (sinks). Accounting for this C budget is required for understanding human impacts on climate, guiding mitigation strategies, and informing future projections. This fact sheet illustrates an initial attempt to piece together the full C budget for the state of Maine.

Key Findings

- GHG emissions in Maine are dominated by burning fossil fuels, primarily from the transportation sector, but with a sharp decline in electric power emissions over the last decade.
- Carbon 'offsets' are estimated as 55% for forest growth and 75% for the total annual C cycle.
- Critical uncertainties in the budget arise from undersampled or unknown components. Improved assessments require advances in stock quantification and flux monitoring.

Major Sectors of Maine's Carbon Budget

The simplified C budget of Maine shows estimates of current stocks and annual fluxes in million metric tons of carbon (MMTC, from 2006 to 2016) for the major components. Maine's land-base currently stores more than 2 billion tons C, primarily (~75%) in forest soils. Of the 5.1 MMTC emitted annually by the sources shown, 2.8 MMTC (~55%) is offset by C uptake from forest growth.

Fossil Fuels

The plot below shows C emissions over time (since 1990) from the major sources of fossil fuel combustion in Maine. Carbon emissions from fossil fuel combustion in Maine peaked in 2002-04, and have been declining by ~3% per year since. Despite the decline, transportation emissions have maintained a steady pace and currently account for more than half of total emissions.

Forestry

Trees take up C from the atmosphere through photosynthesis and adds it as biomass. As the C cycles through the ecosystem it is either returned to the atmosphere through decomposition or incorporated into the soil. In managed forests, live biomass is also removed in harvest and that C can be made into short- (e.g., pulp) or long- (e.g., sawlogs) term products. About 89% of Maine consists of forests (the most of any state), which account for the vast majority of C uptake and storage in this budget.

Forest Component	2006 Stock (MMTC)	2016 Stock (MMTC)	Stock Change (MMTC/yr)
Live Biomass	385	412	2.679
Dead Organic Matter	45	47	0.132
Soil Carbon	1,612	1,613	0.133
Total Forest Carbon	2,042	2,071	2.940

Agriculture

Carbon in crop residues can be incorporated into the soil, depending on management practices across the diversity of Maine's 7,600 farms. Livestock are a major source of the emissions from this sector.

Urban Areas

In built environments, the C stored in trees, gardens, lawns, and wooden structures from residential areas and parks are increasingly important in keeping C out of the atmosphere.

crsf.umaine.edu/forest-climate-change-initiative/carbon-budget

Figure 1. First version of carbon fact sheet released in February 2020. Full details available at https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/

In February, CRSF and the Forest Stewards Guild sponsored an interactive Science & Practice Forum (presentations and audio files of the event can be accessed at www.crsf.umaine.edu/forest-climate-change-initiative/fcci-science-practice-forum) to catalyze scientist-manager discussions about current research and stakeholder needs, grow Maine's forest climate adaptation community of practice, and provide useful information for the work of the Maine Climate Council. Each session consisted of an overview by FCCI speakers about what they are doing to address the specific areas related to forest climate change; researcher specialty and forest climate adaptation questions they are working on; and a facilitated Q&A discussion. Themes of the day included forest ecology, operations, and socioeconomics as well as communicating with landowners and the public about climate change.

Intelligent GeoSolutions

crsf.umaine.edu/forest-research/igs

Sophisticated machine learning algorithms provide near real-time, highly accurate geospatial information about forest attributes of high relevance to forest management, scalable to large areas using satellite imagery and USFS FIA plot data. Using such algorithms, the IGS team developed and had now released the Maine Forest Ecosystems Status and Trends App, an interactive forest resource mapping application designed to support management planning and mitigation of spruce budworm impact.

ForEST
Maine Forest Ecosystem Status and Trends App

ForEST enables the visualization and interpretation of high-resolution map data relevant to SBW mitigation and land use planning. Easily navigable, the App (Figure 2) allows users to view state-of-the-art maps of forest conditions derived from satellite imagery, explore regional budworm population monitoring data, evaluate forest risk in areas of interest, identify natural resource tradeoffs, and download GeoPDFs. Current map layers include statewide pheromone trap locations with annual spruce budworm moth trap catch, and maps of forest vulnerability to budworm, percent balsam fir (primary spruce budworm host species), and areas of high probability of Canada lynx occurrence, all derived using Landsat satellite imagery and plot data from the USFS Forest Inventory and Analysis program. The mapped area (currently encompassing ~ 4 million acres of forestland) will be expanded statewide over the coming months.

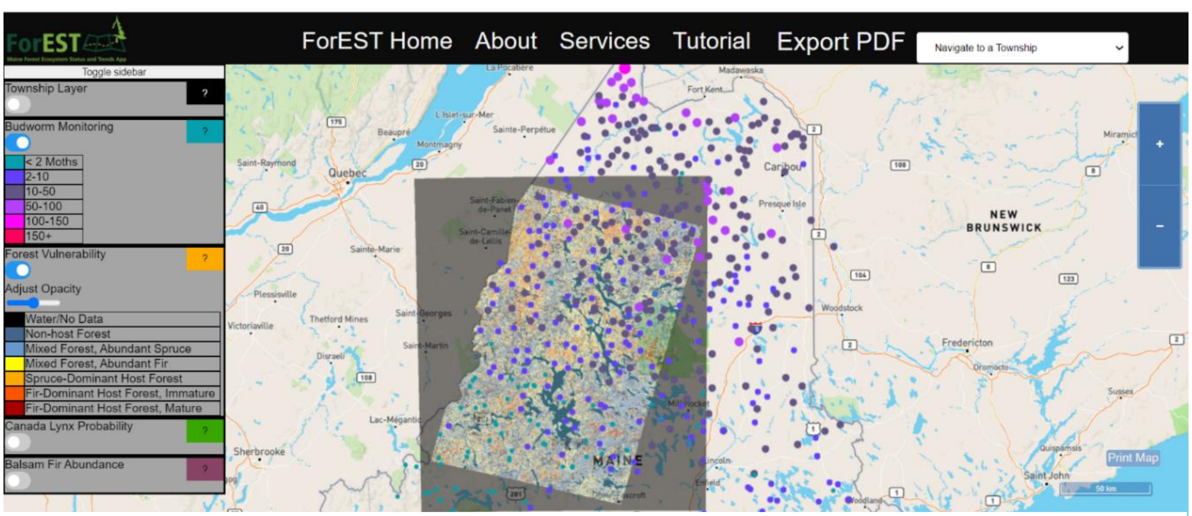


Figure 2. Screen shot of ForEST App landing page. ForEST is accessible at https://forestapp.acg.maine.edu.

Nature-Based Tourism

crsf.umaine.edu/nature-based-tourism

Natural resource-based economies, such as forestry and tourism, are important to Maine's citizens as they support rural livelihoods and stewardship of the environment. These industries play a vital role in the culture, quality of place, and economic development of Maine's rural communities, as well as in the overall economy of the state. For example, tourism in Maine provides both economic and non-economic value to its citizens, including nature conservation, cultural heritage maintenance and pride, and infrastructure and facility improvement. Maine's outstanding tourism assets, along with the diversity of outdoor recreation opportunities, attract millions of visitors annually to and within Maine. Challenges to capturing growth opportunities relate to changes in visitor travel behavior, economic and health crises, limited tourism planning, and changing environmental conditions. By regularly gathering, analyzing, and communicating information about the trends and factors that influence tourism development in Maine we expect to increase the efficiency of and opportunities for Maine's tourism industry.

Related to her nature-based tourism work, Dr. Sandra De Urioste-Stone was awarded a grant from the National Science Foundation Research Traineeship program to support the preparation of future leaders in the STEM (Science, Technology, Engineering, and Math) workforce. The Enhancing Conservation Science and Practice program at the University of Maine is designed to train the next generation of interdisciplinary environmental conservation leaders.

Multiuse trail in Orono Land Trust, April 2020. Photo courtesy M.Fergusson.

Highlights of the Nature-Based Tourism program from 2019–20 include ongoing progress to learn from experts on how to improve Maine's forest-based economy and address associated uncertainties and risks, such as changing socio-demographics, shifting markets, and responding to changing climate conditions. The Fostering Coastal Community Resilience in Maine project focused on how climate change impacts the coastal tourism assets in the region, how these changes impact the consumer base, and how to effectively develop adaptation strategies to take advantage of opportunities and anticipate negative effects from climate change. Insights from these studies are crucial to the resilience of natural-resource dependent rural communities and industries in Maine.

CRSF Project Reports

Maine Forest Industry Sub-Sector Analysis

Progress Report (Year 2 of 3)

SANDRA DE URIOSTE-STONE (PI), PARINAZ RAHIMZADEH-BAJGIRAN, AARON WEISKITTEL AND ADAM DAIGNEAULT

SUMMARY

Maine's rural communities and natural resources-based industries rely heavily on the products and services provided by forest ecosystems. Given the complexity of the state's forest systems, with transition forests in early and mid-successional stages resulting from prior disturbances, the influence of climate change should be more evident than in other regions. Hence, the importance of this research to address the impacts of climate change on land cover and management. Our research will enhance the resilience of forest socio-ecological systems (SES) by integrating geo-spatial, economic, and social science analyses, and developing solutions-driven approaches to climate change.

Our study contributes to USDA-AFRI's goals to promote science driven solutions, conduct engaged research, increase adaptive capacity of forest SES to climate variability, and foster reduction of greenhouse gas emissions. The study utilizes a transdisciplinary approach to develop generalizable models for effective climate change adaptation and mitigation.

Objectives

Our research aims to develop and validate an integrated framework to assess and enhance the resilience of forest SES to climate change. We pursue this through four targeted research objectives

- Objective 1: Assess forest resources industry stakeholder awareness of climate variability and consequences on the landscape and ecosystem services, perceptions of vulnerability of forest SES, and land management decisions in response to climate change.
- Objective 2: Link stakeholder perceptions of consequences of climate change with simulated and remote sensing derived changes of forest condition.
- Objective 3: Use an integrated modelling framework to quantify and map the potential physical and socio-economic effects of climate change, forest policy, and landowner adaptation to these pressures on forest composition, structure, and health at a spatial resolution relevant to managers and other stakeholders.

- Objective 4: Jointly identify best management strategies to increase socio-ecological resilience of forest systems and opportunities to enhance ecosystem services along the forest supply chain.

Approach

We are using a holistic, embedded sequential mixed methodologies approach (Creswell 2014), where multiple qualitative and quantitative social, economic and biophysical methods are applied and combined. The use of multiple research methodologies allows for triangulation across designs (Patton 2015); addresses the complexity of the problem that requires multiple data types (Creswell et al. 2007); and generates stakeholder-driven strategies to enhance the resilience of the industry. The methods (Figure 3) used include:

- A total of 20 semi-structured interviews (Creswell, 2013) with forestry stakeholders in Maine.
- A Nominal Group Technique (NGT) used to elicit expert opinions from the Cooperative Forestry Research Unit (CRFU) to rank the importance of climate change effects on forest management in Maine (Delbecq et al., 1975).
- An online questionnaire used to measure stakeholder climate change risk perceptions (Figure 4); knowledge and experience with climate change; forest management practices; motivations and barriers to incorporating climate change adaptation practices; and sources of information trusted (Figure 5).
- A spatially explicit vulnerability assessment model (VAM) was developed to map the vulnerability of Maine's forest sector to climate change by combining biophysical and social indicators of exposure, sensitivity, and adaptive capacity.
- A modified version of the Maine Integrated Forest Ecosystem Service (MIFES) market model developed by Daigneault et al. (2017) to identify how northern Maine's forest ecosystem service (FES) supply chain could be affected by climate change, land use policy, and landowner adaptation efforts.

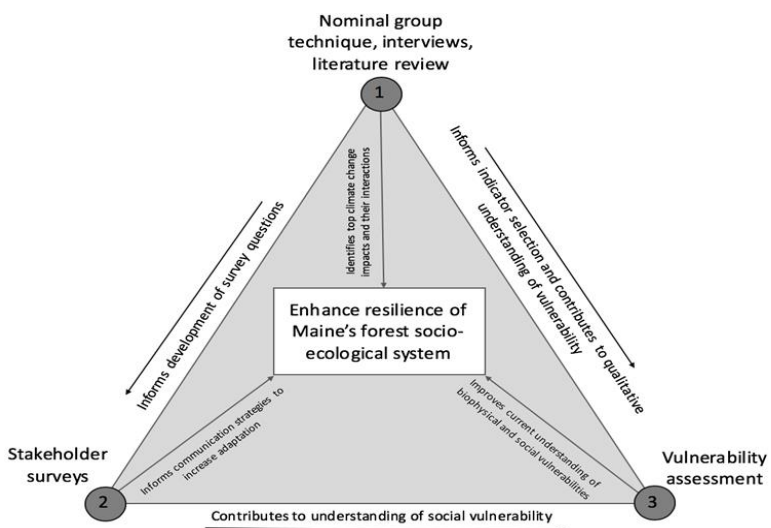


Figure 3. Research Process (figure developed by A. Soucy).

Key Findings

- Maine's forest stakeholders have high risk perceptions regarding climate change impacts on Maine's forest ecosystems and Maine's forest industry.
- Stakeholders identified the greatest and most likely climate change impacts as: forest health threats imposed by insects and pathogens, extreme precipitation events, shifts in forest composition, invasive species, and changes in forest productivity.
- While many of the climate change impacts stakeholders discussed in interviews and the NGT were perceived as a threat to forest ecosystems and the forest industry (e.g., insects and pathogens, extreme precipitation events), several were actually perceived as a potential opportunity (e.g., changes in forest productivity, shifts in forest composition, and summer drought).
- Forest stakeholders are willing to implement a variety of management strategies as part of their efforts to adapt to climate change, including: enhancing and promoting structural and stand-level diversity, thinning trees, creating early detection and conducting rapid removal of undesired invasive species, and improving road/culvert maintenance.
    - Preliminary findings suggest forest stakeholders perceive insects and pathogens, extreme precipitation events, and winter thaw events as threats to the forest industry, all of which present real challenges to forest ecosystems in Maine based on climate data.
    - Forest stakeholders have less experience with shifts in forest composition and describe their potential as an opportunity, which largely coincides with tree species projections that suggest increases in commercially valuable tree species across Maine.

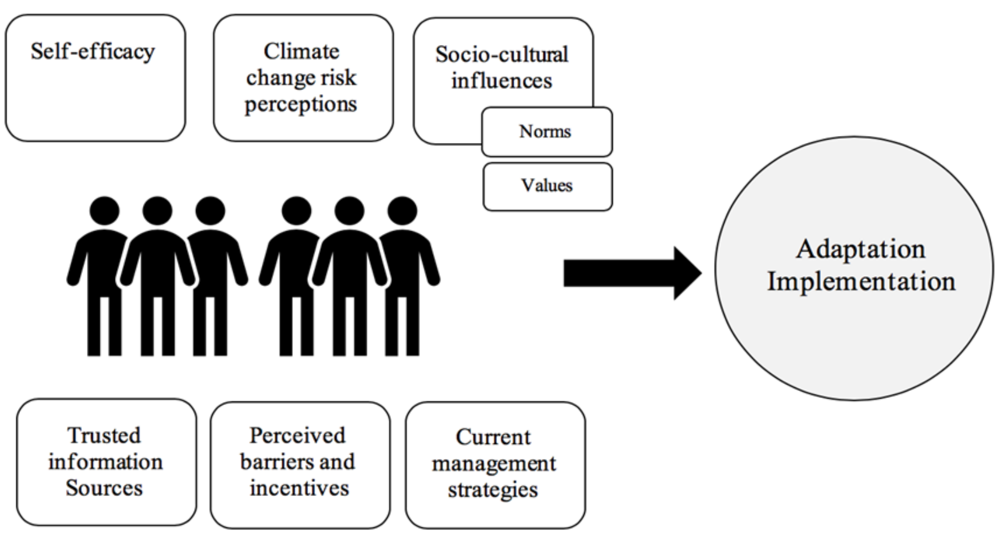


Figure 4. Important factors to consider when communicating with forest stakeholders about climate change adaptation implementation (figure developed by A. Soucy).

- Using geographic information system (GIS) and by integrating biophysical data with socio-economic information via a Vulnerability Assessment Model we were able to identify counties in Maine that may be more threatened by climate change, but also counties that may be well suited to address negative impacts from a changing climate.
- Overall vulnerability assessment indicated that there are five counties mostly located in western and northern Maine that have above state average vulnerability.
- We found that extreme precipitation events have increased the most in western and southern coastal Maine and winter is the fastest changing season in the state. Frozen ground duration is decreasing in southern coastal Maine.
- In regards to sensitivity to climate change, we found that those counties that have more difficulty meeting employment needs (access to a skilled workforce) also have more difficulty meeting employee health needs, and that those highly sensitive counties are concentrated in the northwestern part of the state.
- Analysis indicates that Maine's forests could sequester an additional 3 million tons of carbon dioxide equivalent (MtCO2e) per year under relatively modest carbon prices ($10-25/tCO2e), thereby offsetting about 20% of Maine's current gross GHG emissions.
- Maine could also potentially gain from an increase in market demand for wood-based products, bioenergy, and biofuels, especially if wood is recognized globally as a low-carbon and sustainable source. UMaine analysis suggests that this could result in an additional 3 to 8 MtCO2e/yr in forest carbon sequestration.

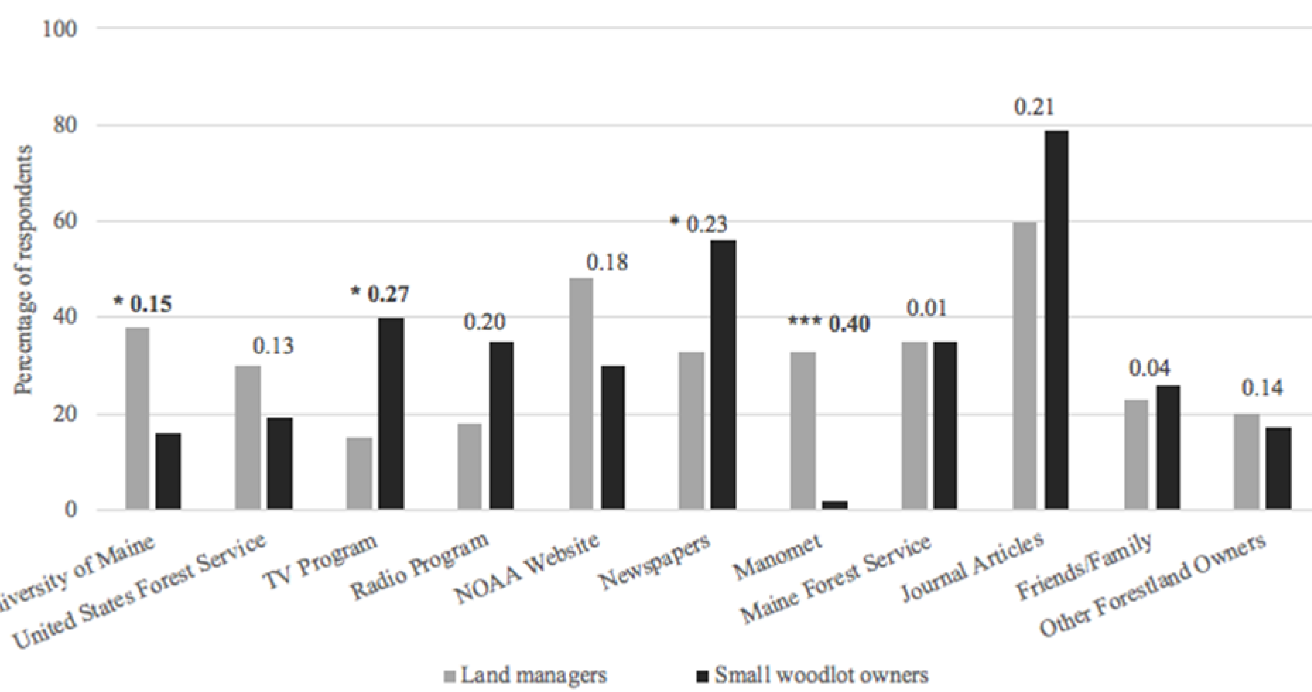


Figure 5. Sources of climate information for stakeholders groups according to survey responses. Significance level (**p value* < 0.05; ***p value* < 0.01; and ****p value* < 0.001) and Cramer's V for chi-square test results for the two stakeholder groups (figure developed by A. Soucy).

OUTCOMES

Accomplishments

- Created a transdisciplinary team of researchers to integrate social and biophysical data relevant to stakeholders.
- Trained four undergraduate students and three graduate students in how to conduct social science research (strategies to conduct rigorous, reliable, and ethical studies) and spatial analysis efforts.
- Increased capacity of faculty and students to effectively work across disciplines and expand collaboration with stakeholders in the state.
- The lead graduate student developed and distributed three infographics (Figure 6) to share study results with industry stakeholders (i.e., members of the CFRU, small woodlot owners, and other partners in Maine). Results have also been shared online, and through multiple workshops.
- Increased capacity of students and faculty to develop effective science communication tools.
- Developed a novel Vulnerability Assessment Model of climate change impacts that integrates biophysical and socio-economic data. Model was tested and validated for the State of Maine.

Significant Challenges

- Due to COVID-19, we had to delay the participatory workshops given travel and gathering restrictions. We plan to modify some of the tools for online delivery, and potentially facilitate several workshops in person if conditions permit.

Future Plans and Opportunities

- Analyze online questionnaire data using SPSS 25 (fall 2020).
- Submit at least two scholarly journal articles (fall 2020-spring 2021).
- Present in at least three scientific conferences (fall 2020 and summer 2021).
- Develop materials for participatory meetings with stakeholders (summer 2020).
- Facilitate participatory meetings with stakeholders (fall 2020 and spring 2021).
- Develop and model additional scenarios beyond state climate policy (spring 2021).
- Work with industry stakeholders to identify key information needs that can be informed by MIFES (spring 2021).

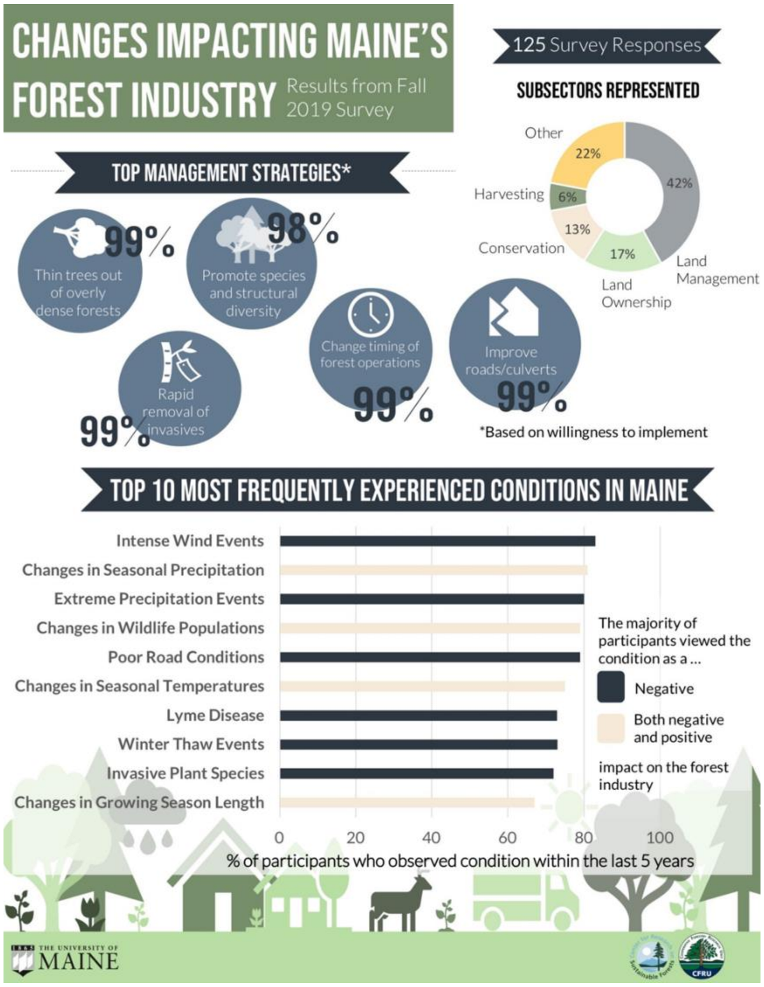


Figure 6. Infographic to share survey results with forest industry stakeholders

Partners / Stakeholders

Our team has interacted with stakeholders from various sub-sectors from the forest industry (land managers; landowners; loggers; transportation; sawmills; pulp and paper mills; bioenergy; professional services; and planners-technical support). The research team has worked with members of the Cooperative Forestry Research Unit and Small Woodlot Owners in Maine to generate data. The team has interacted with the Maine Climate Council, the Forest Climate Change Initiative, Forest Stewards Guild, Manomet, and Schoodic Institute, among others.

References Cited

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th ed.). Thousand Oaks, CA: SAGE Publications Inc.

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousands Oaks, CA: Sage Publications, Inc.

Delbecq, A. L., Van de Ven, Andrew H, & Gustafson, D. H. (1975). *Group techniques for program planning: A guide to nominal group and delphi processes*. Glenview, Ill: Scott, Foresman.

Patton, M. Q. (2015). *Qualitative research and evaluation methods: Integrating theory and practice* (4th ed.). Thousand Oaks, CA: SAGE Publications, Inc.

An Integrated Approach to Quantifying the GHG Mitigation Potential of Natural Climate Solutions from Maine's Working Lands

Progress Report (Year 1 of 2)

ADAM DAIGNEAULT (PI), IVAN FERNANDEZ, AARON WEISKITTEL, ERIN SIMONS-LEGAARD

Summary

Maine's working landscape can play an important part in Maine's GHG mitigation strategy, but the most cost-effective and impactful practices are currently unknown. This research has three distinct components. First, we combine economic and biophysical methods to identify the mitigation potential for 16 different NCS practices in Maine, ranging from modified timber harvesting to timber stand improvement in forests and no-till, biochar and cover cropping on farms. Estimates of GHG sources and sinks at different carbon prices and implementation levels will be developed. Second, we engage stakeholders using focus groups and surveys to gauge the degree that these NCS practices could be implemented, identifying the most valued options and critical impediments to implementation. Potential stakeholders range from large forest landowners to small diversified family farms. Third, we develop alternative scenarios to estimate uncertainty in NCS mitigation potential under a range of alternative climatic, policy, and socio-economic futures. These pathways are likely to impact key components of natural and working lands such as land productivity, desired management practices, global and local commodity prices, and land use (e.g., development). Collectively, this research will accelerate the implementation of NCS in Maine and other states with similar goals and land management systems.

Objectives

- Conduct a benchmark analysis of NCS practices that are applicable to Maine, including their cost and GHG mitigation/C sequestration potential.
- Identify cost-effective and efficient opportunities to implement Natural Climate Solutions in Maine
- Work with farmers and foresters to identify technical, financial, and policy barriers to implementing NCS on Maine's land
- Support the work of the newly formed Maine Climate Council (MCC) and Governor Mills' executive order for Maine to be carbon neutral by 2045.
- Develop an outreach plan for project partners to engage with policymakers and farmers.

Approach

1. **Mitigation Analysis**. Combine economic and biophysical methods to identify the mitigation potential for NCS practices in Maine, ranging from modified timber harvesting to timber stand improvement to no-till, biochar and cover cropping. We have initially identified 10 forestry and 6 agricultural practices to evaluate.

2. **Stakeholder Input**. We will solicit feedback via focus group discussions and surveys about the initial findings developed in #1. This will help us better understand whether practices we estimate as cost-effective might work in the real world. Potential stakeholders include large forest landowners, conservation land managers, family forest owners, large commercial farmers from key Maine commodities (e.g., potatoes, lowbush blueberries), small-scale diversified farmers, and dairy farmers.

3. **Alternative Pathways.** We will couple the findings from components 1 and 2 with the development of alternative scenario pathways based on the IPCC's shared socio-economic (SSP) and relative concentration pathway (RCP) frameworks. This approach will allow us to estimate potential uncertainty in NCS mitigation potential under a range of climatic, policy, and socio-economic futures. These pathways are likely to impact key components of natural and working lands (NWL) such as land productivity, desired management practices, global and local commodity prices, and land use (e.g., development).

Key Findings

- Draft analyses have been conducted for several forest and agricultural practices. Forestry practices are generally cheaper to implement than agricultural practices, and other sectors of the economy (e.g., electricity, transportation)
- The initial findings have estimated that Maine's forests[1] could sequester an additional 0.2 to 4.3 million tons of carbon dioxide equivalent per year ($MtCO^2e/yr$). The most effective practices were found to be a) increasing clearcutting area and replanting with spruce, and b) extending the average age of a stand that can be harvested from 50 to 85 or 100 years. Implementing these practices would cost about $4 to $72 million per annum, equivalent to $10 to $20/$tCO^2e$ (Figure 7).
- We estimate that doing NCS practices on Maine's agricultural lands could reduce the state's GHG emissions by 0.3 to 0.9tCO^2/yr. The most cost-effective practices included constructing anaerobic digesters on dairy farms and amending crop and pastureland soils with biochar.

[1] N.B. our study area only encompassed 10 million acres of Maine's forest. Results for all but avoided conversion and afforestation could be scaled to estimate the impact on all of Maine by using a scaling factor of 1.5.

Implementing these practices would cost about $8 to $45 million per annum, equivalent to $25 to $60/tCO²e or more (Figure 8).

- For context, Maine's forests have sequestered an average of 12 MtCO²e/yr over the past decade, equivalent to removing about 70% of the state's GHG emissions, while Maine's agricultural sector has emitted about 0.4 MtCO²e/yr.
- Additionally, most climate mitigation studies estimate that carbon prices should be $40 or more.

OUTCOMES

Accomplishments

- Draft mitigation analysis has been summarized and distributed via an April 2020 report.
- Findings have been presented during 5 stakeholder meetings held across the state, including the Maine Climate Council's January 2020 meeting.
- Results have been incorporated into the Natural and Working Lands Working Group's recommendations to the Maine Climate Council.
- Analysis has identified that cost-effective mitigation can be achieved, especially in the forest sector, particularly when compared to GHG mitigation costs in other sectors of the economy (e.g., electricity generation, transportation).
- Furthermore, we have identified cost-effective forest management options that increase forest carbon sequestration but also maintain a steady flow of wood supply, thereby a win-win for Maine's environment and forest economy.

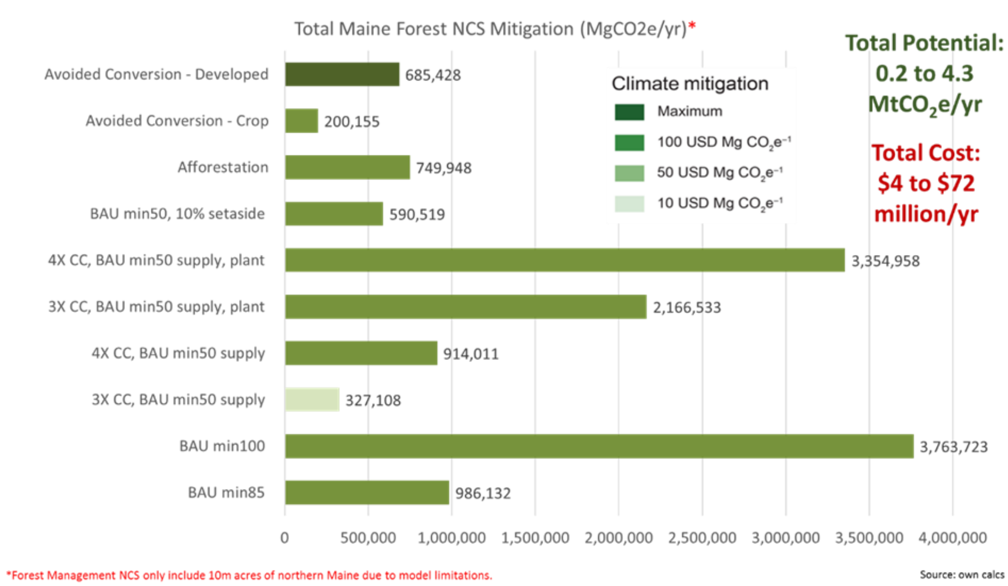


Figure 7. Total annual Maine forest mitigation by NCS practice (MtCO²e/yr)

Significant Challenges

- Covid 19 has limited our ability to conduct farmer and forester focus groups and engage in stakeholder outreach. We will turn to virtual focus groups in the fall, if required.

Future Plans and Opportunities

- Refine analysis based on stakeholder input
- Conduct farmer and forester focus groups to identify opportunities and barriers to implementing NCS.
- Develop climate and socioeconomic scenarios with accompanying narratives to assess impacts of NCS policy on Maine's economy and environment.
- Produce final report and related manuscripts by January 2021.

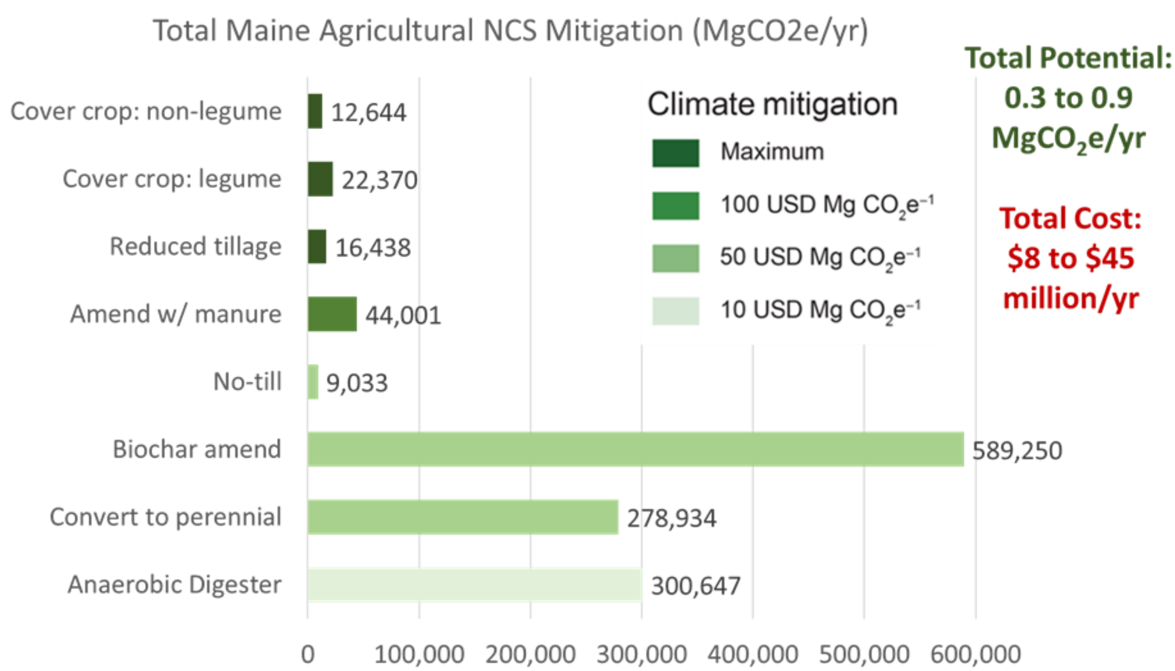


Figure 8. Total annual Maine agriculture mitigation by NCS practice ($MtCO^2e/yr$)

Partners / Stakeholders

Northern Institute of Applied Climate Science, USDA Northern Forests Climate Hub; The Nature Conservancy, Maine; Maine Farmland Trust; Maine Climate Table; American Farmland Trust; Wolfe's Neck Center for Agriculture and the Environment; The Nature Conservancy, Massachusetts; Clark University; Colorado State University.

Assessing and Monitoring the Influence of Forest Management Practices on Soil Productivity, Carbon Storage, and Conservation in the Acadian Forest Region

Year 2 of 4

JOSHUA PUHLICK (PI), MARIE-CÉCILE GRUSELLE, IVAN FERNANDEZ

Summary

This project involves using empirical soils data from across the Acadian Forest Region to inform best management practices related to soil productivity, carbon storage, and conservation. As part of the project, researchers are evaluating soil nutrient status, soil carbon storage, and soil compaction on Maine Adaptive Silviculture Network (MASN) installations. On two installations in northern Maine, soils supporting northern hardwoods were evaluated before and after summer timber harvesting. Before harvesting, nutrient stocks and metrics related to soil productivity were calculated using results from laboratory analyses on soils collected from quantitative soil pits. The results from statistical models indicate that soil properties will be drivers of future species composition and carbon trajectories, and that these trajectories will likely vary by installation. Soil compaction was measured as the difference in bulk density between trails and non-trafficked areas. A key finding was that soil moisture and the first machine of the relatively new hybrid harvesting system influenced the effectiveness of slash matting. The soil compaction results are important in the context of climate change as more summer logging is expected to occur in areas traditionally cut in the winter because of longer frost-free periods and more winter precipitation occurring as rain.

Objectives

A major goal of this project is to evaluate the influence of different forest management practices on soil productivity, carbon (C) storage, and conservation across operational-scale research installations in Maine. Specific objectives included identifying forest management practices and soil properties that: (1) promote adequate nutrient availability that supports forest sustainability, (2) maintain or enhance soil C stocks, and (3) minimize compaction and erosion.

Approach

- In 2018 and 2019 (before and after timber harvesting), soil samples were collected in northern hardwood stands managed by J.D. Irving Limited and Seven Islands Land Company.
- The forest management practices evaluated for their influence on soils include crop tree release, partial harvesting, and control (no cutting since the 1950s to 1970s).

Undergraduate researchers Emily Roth and Joshua Goldsmith measuring downed woody materials after timber harvesting at one of the MASN installations. Photo courtesy Joshua Puhlick.

- Soil samples from 52 quantitative soil pits and approximately 150 organic horizons were collected over both years.
- Live and standing dead trees as well as downed woody debris were measured in association with quantitative soil pit locations.
- 550 soil samples were collected to determine mineral soil bulk density for evaluating soil compaction after harvesting.

Key Findings

Nutrient Status

- The carbon to nitrogen ratios of soil organic horizons indicated that nitrogen in organic materials exceeded microbial growth requirements and that excess nitrogen was available to plants.
- For the organic horizon plus mineral soil from the top of the B horizon to a depth of 30 cm or bedrock, P, Ca, Mg, and K stocks varied by installation.
- The percentage of coarse fragments in the mineral soil or depth to bedrock influenced the amounts of certain nutrient stocks, but the relationships often varied in magnitude and direction by installation.

- The effective base saturation in the upper B horizon differed between installations, with one installation having values shown to adversely affect sugar maple.

Soil Compaction

- Mineral soils with low bulk densities were the most susceptible to compaction.
- Locations along trails closest to landings were susceptible to compaction.
- Soil moisture and the first machine influenced the effectiveness of slash matting.
- Methods were developed for sampling soils with mixed horizons due to logging.

OUTCOMES

Future Plans and Opportunities

- Soils on an additional MASN installation in northern Maine will be sampled during Summer 2020 for similar analyses.

Partners / Stakeholders

Greg Adams, Irving Woodlands, LLC; Ian Prior, Seven Islands Land Company; Eugene Mahar, LandVest Timberland Division; Gordon Gamble, Wagner Forest Management; Kenny Fergusson, Huber Resources Corporation; Brian Roth, Cooperative Forestry Research Unit; Keith Kanoti, University Forests Office; Pat Sirois, Maine SFI Implementation Committee (Maine SIC); Greg Lawrence, Northeastern Soil Monitoring Cooperative; Scott Bailey, Northeastern Soil Monitoring Cooperative; Charles (Tat) Smith, University of Toronto; Nicholas Butler, USDA Natural Resources Conservation Service; Jamin Johanson, USDA Natural Resources Conservation Service.

Undergraduate researchers Emily Roth and Joshua Goldsmith collecting an organic horizon at one of the MASN installations. Photo courtesy Joshua Puhlick.

Fostering Coastal Community Resilience in Maine: Understanding Climate Change Risks and Behavior

Year 3 of 4

SANDRA DE URIOSTE-STONE (PI), PARINAZ RAHIMZADEH-BAJGIRAN

Summary

Maine's dependence on natural assets to attract tourists to coastal areas makes the nature-based tourism industry, and the economies of surrounding rural communities, sensitive to changes in climate and weather conditions. Hence, an improved understanding of how climate change will impact the coastal/marine tourism assets in the region, how these changes will impact the consumer base, and how to effectively develop adaptation strategies, becomes crucial to the resilience of these natural-resource dependent coastal communities. Our research aims to enhance the ability of coastal tourism destination communities to cope with the negative effects of and capitalize on emerging opportunities that ecological and travel modifications resulting from climate change might bring using effective collaboration models.

Figure 9. Word cloud with most frequently mentioned terms during interviews (figure developed by L. Horne).

Objectives

- Investigate coastal tourism stakeholder climate change risk perceptions; identify current and planned mitigation strategies; assess current and likely adaptive behavior in response to climate change risk; and identify socio-economic and institutional barriers to adaptation.
- Measure visitor climate change risk perceptions, and estimate resulting potential behavioral changes (e.g., destination, activity participation, seasonal visitation patterns) to the risk of climate change in coastal destinations.
- Study the current effects of climate on coastal tourism destinations, coastal-scapes, and other natural assets using social, meteorological and satellite remote sensing data in the region.
- Integrate and share results with community stakeholders to jointly develop best practice strategies to increase the adaptive capacity of the coastal tourism industry in Maine.

Approach

Research activities are being conducted in collaboration with stakeholders in three selected Maine coastal tourism destinations: Camden, Machias, and Mount Desert Island. We are using an overarching comparative case study methodology that examines a bounded contemporary phenomenon—a case—that considers the conceptual, temporal, physical, and the social spaces for boundaries (Yin, 2014). We are applying a comparative case study with holistic analysis of each case (Creswell, 2013).

We are using a three-phase mixed methods approach with a convergent research design (Creswell, 2015). Phase 1 consists of qualitative interviews with an embedded pile sort activity. Phase 2 relies on a quantitative visitor survey and a biophysical and social vulnerability assessment specific to these three tourism destinations. We are collecting and analyzing data from each phase separately. In Phase 3, we are integrating data and will facilitate a series of participatory planning workshops to share our findings with stakeholders and jointly develop climate change adaptation strategies for each tourism destination in collaboration with stakeholders. The methods used include:

- A total of 38 semi-structured phenomenological interviews (Creswell, 2013) conducted with tourism stakeholder in the study regions in Maine. A pile sort activity was embedded within the interviews to identify group cognition.
- A mixed-mode survey was administered to visitors of MDI to identify factors contributing to tourist climate change risk perceptions, and adoption of coping behaviors to respond to climate change. We surveyed a total of 1,353 visitors on-site, and 480 of those completed the follow-up survey responses, with a response rate of 35.48%. Data are currently being analyzed.
- A geo-spatial integrated vulnerability assessment model is in development, whereby biophysical factors, social and economic variables. Currently we are collecting and evaluating several climatic, biological, and socioeconomic indicators to be included in our model. The final product will create a vulnerability map identifying areas at greater risk to climate change impacts within tourism destinations, referred to as vulnerability hotspots.

Key Findings

- Many participants have discussed building community resilience in terms of leveraging resources and developing partnerships with other local businesses and organizations. Strong social networks resulting in frequent collaborations, especially between non-profits, appear to be key for bolstering destination resilience and addressing community concerns, such as poverty, natural resource conservation, and economic development. These partnerships have also been effective in sharing knowledge, resources, and skillsets across stakeholder groups and between tourism destinations. Natural resource dependent livelihoods and personal outdoor


Undergraduate student researchers during field work in Acadia National Park.

recreation habits were important for connecting participants with first-hand observations of environmental changes and a valuation of environmental protection.

- While partnerships, connections to place, and a shared valuation of the environment were all factors contributing to resilience, participants across destinations discussed outdated infrastructure as a major source of climate change vulnerability. In Machias, a destination that can be characterized as in the exploration phase of Butler's Tourism Area Life Cycle (TALC) model, the lack of economic development was described as a barrier to destination resilience. In contrast, MDI participants expressed concern for overdevelopment and crowding as visitation continues to increase on the island, creating new environmental and social pressures for the area.
- Participants have overall demonstrated high awareness and concern for climate change impacting coastal Maine. The increasing tick population and resulting spread of Lyme disease is of especially high concern among the National Park Service, non-profit land managers, and business owners. These participants have repeatedly discussed the need for more research to understand visitor perceptions of ticks and resulting behavioral changes in relation to visitor education and land management decisions. Other climate change impacts of high concern are increased storms.
- Further, among the terms most frequently used by participants during interviews include people, know, climate and change (Figure 9). Participants usually referred to climate change in terms of the implications to humans. It was also mentioned climate change in connection to having or lacking knowledge on the topic.
- Preliminary analysis from the visitor survey show that over 75% of visitors to Acadia National Park expressed some level of climate change concern with almost half indicating they were very concerned about climate change. When asked about likely climate change impacts to MDI and Acadia National Park, visitors indicated that the increased presence of ticks and mosquitoes, an increase in heat waves and extreme weather events, a longer summer season, and increased visitation to Acadia National Park were the most likely outcomes related to climate change. Not all of these impacts would necessarily result in reduced visitor numbers or negative consequences to the destination as a longer summer season was expected to increase visitation overall and extend seasonal tourism.

- According to several participants, disease outbreaks, increased mosquitoes, increased ticks, increased rain, and extreme weather events were most likely to decrease outdoor recreation activity. Actions participants were most likely to adopt in case of climate change impacts to outdoor recreation resources include pursuing other outdoor recreation/tourism activities (activity substitution), visiting MDI and Acadia National Park during another time of year (temporal substitution), or substituting another location in the U.S. (spatial substitution).

OUTCOMES

Accomplishments

- Established a community of learning whereby faculty, graduate students, and undergraduate students support and learn from one another.
- Created a team of researchers and partners seeking to integrate social and biophysical data relevant for decision making.
- Trained four undergraduate students and four graduate students in how to conduct social science research (strategies to conduct rigorous, reliable, and ethical studies) and spatial analysis efforts.
- Increased capacity of students and faculty to develop effective science communication tools.
- We are collaborating with partners to develop a communication and facilitation plan to share study results, and conduct participatory activities to identify strategies and develop planning tools to help enhance the ability of community destinations to cope and respond to changing conditions.
- This project will support tourism industry stakeholders and community partners enhance their ability to respond to negative effects of climate change, while taking opportunities that are brought by changing climate conditions.

Significant Challenges

- Have had numerous potential participants live in Maine only during summer and early fall, hence making scheduling interviews difficult or impossible since the start of the grant. Many tourism business providers are only present in the area during peak tourism season, with limited time for other activities besides running their businesses.
- Experienced some difficulty recruiting interview participants due to COVID-19. We have switched to phone interviews to ensure the safety of all research participants and researchers. Unfortunately, this has eliminated the ability to do pile sorts with participants. Furthermore, we

acknowledge that potential participants are under increased stress due to the uncertainty surrounding COVID-19 and may be less willing to participate in interviews.

- We had to delay the participatory workshops given travel and gathering restrictions. We plan to modify some of the tools for online delivery, and potentially facilitate several workshops in person if conditions permit.

Future Plans and Opportunities

- Continue interviewing nature-based tourism stakeholders from all sites with a focus on MDI and business owners (summer 2020).
- Conduct phenomenological data analysis (summer and fall 2020).
- Analyze pile sort data using SPSS (summer 2020).
- Compare newly developed social indicators with biophysical GIS layers to create a vulnerability map to use for collaborative planning meetings with tourism stakeholders (summer and fall 2020).
- Analyze survey data using SPSS 25 (summer 2020).
- Integrate data from phases 1 and 2 (fall 2020).
- Submit at least three scholarly journal articles (summer and fall 2020).
- Present at two scientific conferences (spring and summer 2021).
- Develop materials for the participatory meetings with stakeholders (fall 2020; spring 2021).
- Facilitate participatory meetings with stakeholders (fall 2020; spring 2021).

Partners / Stakeholders

Acadia National Park; Schoodic Institute; Sunrise County Economic Council; DownEast; Acadia Regional Tourism; Maine Woods Consortium; Appalachian Mountain Club; University of New Hampshire; Maine Medical Research Institute.

References Cited

Creswell, John W. (2015). *A concise introduction to mixed methods research*. Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Yin, R. (2014). *Case study research: Design and methods*. (5th Ed). Thousand Oaks, CA: Sage Publications, Inc.

A Resilience Indicators Approach to Ensuring Equitable, Objective, and Continued Investment in Northern Border Communities

Year 1 of 2

ADAM DAIGNEAULT (PI), AARON WEISKITTEL, SAMUEL ROY

Summary

The Northern Border's economy depends heavily on the health and sustainable management of its forest. In fact, the relative contribution of forested lands to the gross domestic product for most counties in the four-state Northern Border Region is among the highest in the United States (4-5%). The abundance of forestland in the Region can be a blessing and a curse because many rural communities are primarily dependent on a single ecosystem service and the tax revenue that related industries provide. Several communities in the Region have been dependent on a single industry for decades, facing hardship when markets shift and demand is reduced (e.g., mill closures), leading to crises of economy, culture, and identity (e.g., new manufacturing, recreation). Furthermore, the region's forest faces increasing pressures from land use change, shifts in ownership, and invasive pests and other environmental stressors. This research project uses a mixed methods approach to measure and enhance the socio-economic resilience of forest-dependent communities across the Northern Border Region. To ensure equitable, objective, and transparent investment in the region's rural communities – focusing on a path towards continued prosperity in the region – we are undertaking a multi-state approach to develop, quantify, and track a broad set of resilience indicators.

Objectives

1. Use publicly available data to construct a time series of quantitative socio-economic resilience indicators for all communities located within the Northern Border Region;
2. Analyze household data to from 'distressed' areas of the Region to assess both the current perceptions and future aspirations of residents and visitors in these specific communities;
3. Conduct statistical analyses to compare the resilience indicators collected for these communities against other regions of the U.S. with similar issues and geographies to identify the most relevant metrics for benchmarking and building socio-economic resilience; and
4. Integrate steps 1-3 into a framework of pathways that the Region's rural communities can take to build resilience and promote economic development. This building of this framework will be iterative, incorporating feedback obtained through community meetings, factsheets, and an interactive map that could be linked with the Northern Borders Regional Commission's map of the Region on the website.

Key Findings

The project commenced in January 2020 and is still very much in the data collection stage. Regardless, we have produced preliminary results for various resilience metrics for the Northern Border region, including total socioeconomic resilience (Figure 10) and separate components of that index. Total resilience is estimated to be highest in areas surrounding Burlington, VT, Hanover, NH, and Saratoga Springs, NY and lowers in Downeast Maine, Northern New Hampshire, and parts of the Adirondacks. As illustrated in Figure 11a-d, the individual community, social, economic, and housing focused resilience indices all have varying influence on total resilience, although many of these indices are highly correlated in parts of the Northern Border region. Further analysis will identify which of the individual metrics are likely to have the strongest influence on socioeconomic resilience, thereby providing insight on what communities can focus on to maintain or improve their overall well-being.

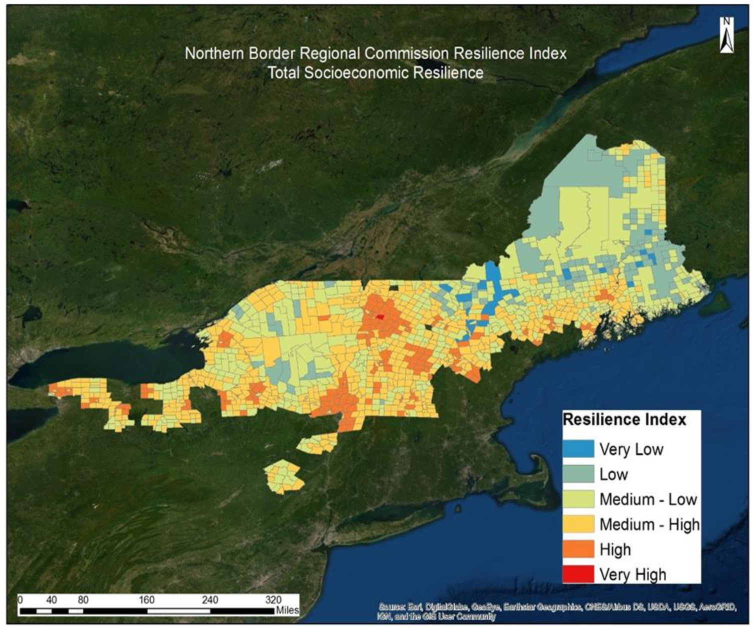


Figure 10. Total socioeconomic resilience index for Northern Border communities (2016)

OUTCOMES

Accomplishments

- Draft quantitative indicators findings have been presented to Northern Border Regional Commission Executive Director.
- Focus on identifying socioeconomic resilience indicators to support, grow, and diversify Maine's rural economy.
- Developed partnerships with researchers and other stakeholders that are committed to improving the cultural, economic, and civic future of Maine.
- Directly involve graduate and undergraduate student researchers to build their personal and professional development.
- Design statewide survey to assess individual perceptions and impacts of Covid-19 on Mainers (to be disseminated in July 2020, target n = 500).

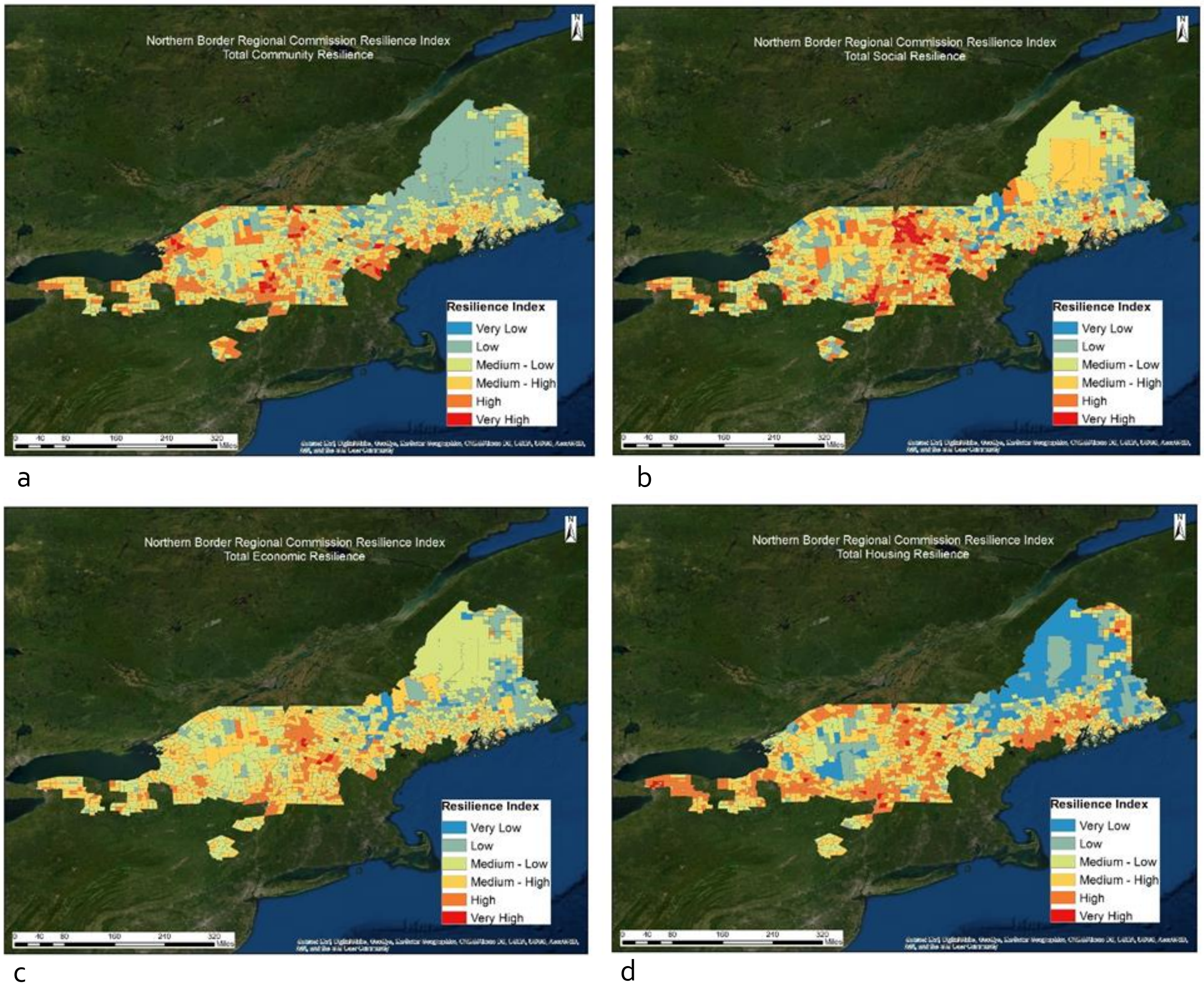


Figure 11. Individual socioeconomic resilience indices for Northern Border communities (2016): a) community, b) social, c) economic, and d) housing.

Significant Challenges

Project collaborators only received funding through USFS JVA in June 2020. This in addition to Covid 19 has limited our ability to conduct focus groups and engage in stakeholder outreach. We will turn to virtual focus groups in the fall, if required

Future Plans and Opportunities

- Continue with activities, as laid out in the work plan/approach discussed above.
- Present interim findings to NBRC executive board in Fall 2020.
- Conduct focus groups and engage in stakeholder outreach

- Build collaboration with UVM and HBRF for community outreach and dissemination of project findings to turn knowledge into action.
- Refine quantitative indicators and analyze drivers of increased/decreased resilience across the Northern Border region.
- Have put language in federal budget appropriations for annual funding to support quantitative metrics for assessing community and socioeconomic resilience in the Northern Border region. Awaiting to hear whether this will be interpreted as intended

Partners / Stakeholders

USDA Forest Service, University of Vermont, Hubbard Brook Research Foundation, Northern Borders Regional Commission

Projecting Carbon Storage and Accumulation of the Maine Ecological Reserves

Year 1 of 2

JOSHUA PUHLICK (PI), AARON WEISKITTEL

Summary

Estimates of carbon (C) storage and sequestration in ecological reserves are needed to inform planning and policy decisions related to mitigating global climate change and C management. In Maine, C accumulation in old forests (last harvested in the late 1800s) can be quite positive and sustained, particularly when all C pools are accounted for (Puhlick et al. 2019). Unmanaged reserves as well as forests managed with silvicultural treatments that maintain or enhance C accumulation over time could achieve additional C-related objectives (Puhlick et al. *In review*). The benefits of C storage and related ecosystem services that ecological reserves can provide could also lend support for the establishment and monitoring of reserves in other states. This project seeks to leverage prior investment in the analysis of ecological reserve data (Kuehne et al. 2018a; Kuehne et al. 2018b).

Objectives

The overall goal of this project is to assess current C stocks and project future C accumulation across the ecological reserves and managed forests of Maine. Specific objectives are to:

- Determine past and current aboveground forest C stocks (live trees and dead wood; Mg ha^{-1}) and average annual net change in C (AAC; Mg ha^{-1} yr^{-1}) using repeat measurements of forest attributes on permanent plots of the Maine Ecological Reserve System.
- Model aboveground forest C stocks (live trees and dead wood) 20 years into the future using inventory data from the Ecological Reserve Monitoring and a regionally calibrated growth model.
- Compare the current C stocks and predicted AAC over time between the ecological reserves and managed forests (using Forest Inventory and Analysis or Maine Adaptive Silviculture Network data) by forest type groupings.
- For individual ecological reserves, compare live tree C estimates derived from the permanent plot inventory data to live tree C estimates derived from LiDAR data.

Approach

- The most recent measurements of forest attributes on permanent plots of the Maine Ecological reserve System as well as soil survey information will be used to determine current C stocks and to model forest C stocks 20 years into the future.

- Model projections of tree growth and mortality will be used to calculate live tree C stocks and estimate dead wood recruitment over time.
- To assess trends, current and projected C stocks and AAC will be graphed for each ecological reserve.
- For ecological reserves within the extent of the New England Enhanced Forest Inventory (EFI) using LiDAR data, live tree C in trees > 10 cm diameter at breast height for individual reserves will compared between the EFI and plot-based estimates.

Key Findings

None to report at this time. Data only recently compiled and the framework for the analyses developed.

References

Kuehne, C., Puhlick, J., Weiskittel, A., Cutko, A., Cameron, D., Sferra, N., and Schlawin, J. 2018a. Metrics for comparing stand structure and dynamics between Ecological Reserves and managed forest of Maine, USA. Ecology 99(12): 2876-2876. doi: 10.1002/ecy.2500.

Kuehne, C., Puhlick, J.J., and Weiskittel, A.R. 2018b. Ecological reserves in Maine: Initial results of long-term monitoring [online]. University of Maine, Center for Research on Sustainable Forests. Orono, ME. Available from http://www.nefismembers.org/documents/ecological-reserves-in-maine-initial-results-of-long-term-monitoring [accessed 29 March 2019].

Puhlick, J.J., Fraver, S., Fernandez, I.J., Teets, A., Weiskittel, A.R., and Kenefic, L.S. 2019. Site quality, disturbance, and vegetation effects on carbon storage and accumulation in old, mixed-species stands in central Maine, USA. Nat. Areas J. 39(4): 429-441. doi: 10.3375/043.039.0406.

Puhlick, J.J., Weiskittel, A.R., Kenefic, L.S., Woodall, C.W., and Fernandez, I.J. In review. Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests.

NSF RII Track 2 FEC: Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency (INSPIRES)

Year 1 of 5

Aaron Weiskittel, University of Maine (PI); Anthony D'Amato, University of Vermont; Ali Abedi, University of Maine; Scott Ollinger, University of New Hampshire; Mary-Kate Beard-Tisdale, University of Maine

SUMMARY

The INSPIRES project started August 1, 2019 and is an interjurisdictional partnership between Maine, New Hampshire, and Vermont. The INSPIRES team currently involves 54 individuals with the majority being faculty from the three states (38; ME = 28, NH = 13, VT = 13), bolstered by undergraduate/graduate students (10) and professional staff (6). Although only in the early stages of the project, the team that has formed is diverse, has strong linkages across jurisdictions, and many of the faculty are early career (48%). The structure of the project is centered around four core research themes, namely: (1) Advanced Sensing and Computing Technologies; (2) Smart Environmental Informatics; (3) Integrated Ecological Modeling; and (4) Quantitative Reasoning Skills in Context. These themes, collectively applied, will build understanding of current and future changes in the Northern Forest in response to ecological and socioeconomic drivers.

The primary focus for Year One was on team building, completion of a project implementation plan, and initiation of inter-jurisdictional research efforts. The goals of the inaugural meeting were to introduce team members, establish regional and theme interactions, provide access for shared files, and develop theme goals. This launch set in motion numerous virtual and in-person meetings regularly conducted by the Core Leadership Team (CLT), individual research themes led largely by early career scientists, and within jurisdictions. Quarterly all-team meetings focus on project and research theme updates and discussion. Individual research

NEW ENGLAND SUSTAINABLILITY CONSORTIUEM

The New England Sustainability Consortium (NEST) is a regional research partnership focused on strengthening the scientific basis for decision-making for sustainability challenges where economic and community development goals need to be balanced with environmental protection.

More information on INSPIRES, including the complete Year 1 report, can be found on the NEST website:

www.newenglandsustainabilityconsortium.org/inspires-smart-data-resilient-forests

themes regularly meet to understand team member research interests, complete strategic materials, including collaborative research agendas, and outline key research milestones by project year. These milestones are essential to monitoring project progress. Likewise, regular intra-jurisdiction meetings across institutions are used to help build team relationships and identify key linkages among jurisdictions as INSPIRES brings together a diverse set of disciplines such as engineering, computer science, ecology, biometrics, ecosystem modeling, and STEM education.

The project implementation plan the team developed provides the necessary structure, governance, strategic assessment, and plans for research, communications, and evaluation. As part of the project implementation plan, the CLT and research themes each completed key strategic materials including logic models, Strengths, Weaknesses, Opportunities and Threat (SWOT) assessments, and stakeholder matrices.

INSPIRES includes a broad array of disciplines (Figure 12) including data science, ecology, and engineering such as electrical, computer, and communications. The digital Big Data framework developed from this effort would be applicable to other forested regions and ecosystems. Most importantly, the effort will help support and sustain this unique forested landscape, which many rural communities rely on for their livelihoods.

Objectives

Maine (ME), New Hampshire (NH), and Vermont (VT) encompass major parts of the complex and highly interconnected Northern Forest Region (NFR), which has a long history of ecological integrity and service to rural communities. In this project, we aim to harness the region's complex landscape and digital information diversity through the creation of a Digital Forest resource, which is our Big Data Science approach to integrating contrasting forest information, ownership, management units, and underlying ecology into a "natural laboratory" that can be used to support hypothesis formulation and testing across the various social-ecological dimensions that comprise the highly complex NFR.

Our efforts address the following overarching science questions:

1. How are spatio-temporal variation and uncertainty in forest extent, composition, health, and productivity driven by: (a) climate; (b) land use; (c) forest management; (d) regulatory policies; (e) invasive insects; (f) other biotic stressors like invasive plants; and (g) natural disturbances?

2. How will these changes affect ecosystem integrity and key services related to: (a) carbon storage/fiber production; (b) habitat/biodiversity; and (c) water quality/surface energy regulation?

Approach

Our overarching hypothesis is that novel Big Data acquisition, integration, and analysis will allow us to address these questions in a way that informs how we approach challenges and opportunities related to the current and future integrity of forest ecosystems. UMS researchers are partnering with UNH and UVM colleagues to advance our fundamental knowledge regarding forest ecosystem resilience and productivity by taking a new convergent approach to analyzing contrasting current and future ecosystem integrity values (fiber/carbon, biodiversity/habitat, and water/energy). Collaboration across the three jurisdictions will also build quantitative reasoning in context skills (QRC) for G6-12 students who will contribute to and use the project's research. The INSPIRES research team is organized into 4 themes:

1. Advanced Sensing and Computing Technologies
2. Environmental Informatics and Analytics
3. Integrated Ecological Modeling
4. Quantitative Reasoning in Context

Primary Year 1 research activities of the INSPIRES project have focused on establishing and building synergies across the broad research team, including recruiting and hiring graduate and undergraduate students and research technicians, as well as developing effective interjurisdictional collaborations with INSPIRES team members across the three jurisdictions.

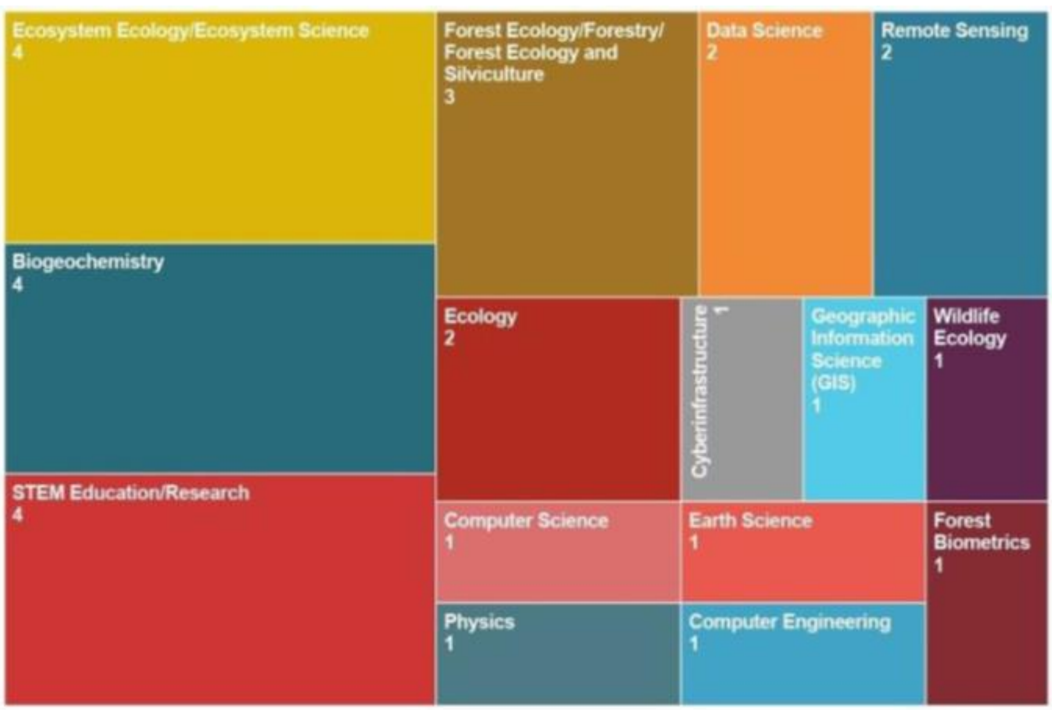


Figure 92. Disciplines currently represented by INSPIRES faculty

OUTCOMES

Accomplishments

- INSPIRES website created and launched in partnership with the New England Sustainability Consortium (NEST)
- Development and completion of project implementation plan, which included a project governance agreement, evaluation plan, communications strategy, strategic assessment, and identification of key stakeholders
- Financial and communications support team established
- Theme 1 prototype of wireless low power soil moisture sensor ready for calibration
- Recruitment and hiring of 2 Post-docs, 8 graduate students, and 3 undergraduate students across the three institutions
- The INSPIRES team has resulted in a number of outcomes with high intellectual merit. This has included 9 submitted proposals (4 to NSF), 4 proposals funded (2 from NSF), 3 publications, and 15 presentations.
- Development of living document for project jargon and acronym dictionary
- Engagement with wide range of regional stakeholders on project objectives and potential applications to regional forest conservation issues
- Baseline survey of project participants completed and analyzed
- New interjurisdictional collaborations initiated through INSPIRES led to new collaborative proposals for future work

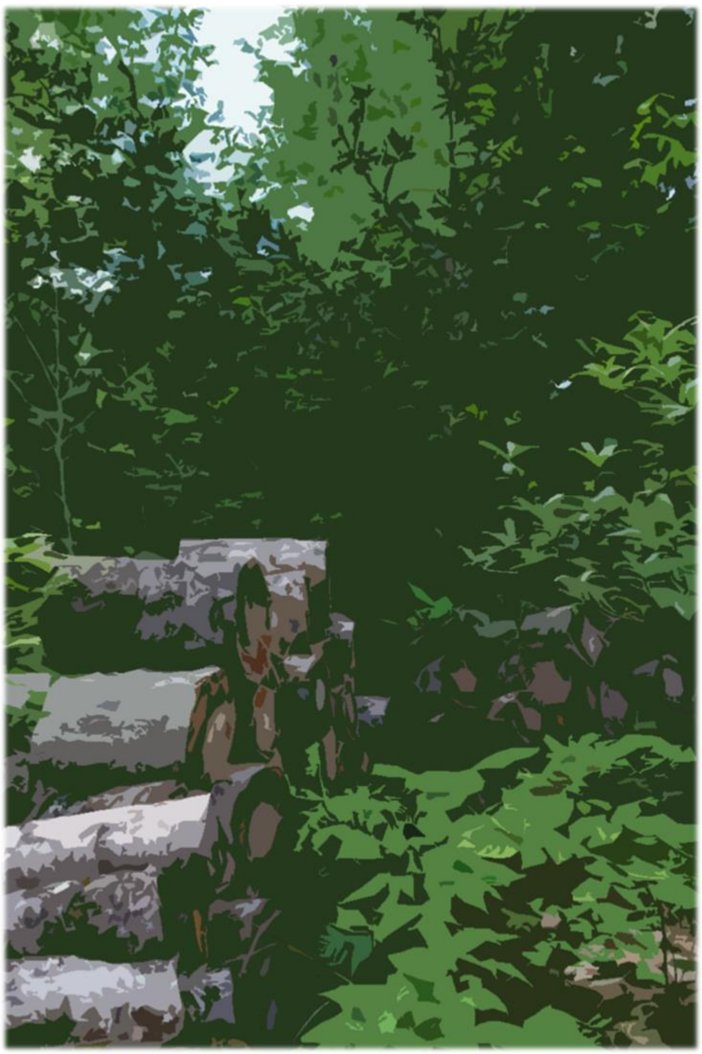
Significant Challenges

Significant challenges arose for the INSPIRES team due to the global pandemic. Travel, hiring, and spending restrictions led to high uncertainty for future planning. Research and field work have been curtailed. The situation has greatly limited access to university resources such as labs, computational resources, and other critical infrastructure needed for the INSPIRES project, which have significantly delayed planned research activities for the spring and summer. Yet progress continues to be made and INSPIRES team members have adapted by modifying and delaying planned activities. Novel opportunities and partnerships are being explored.

Future Plans and Opportunities

Year 2 will continue to build off Year 1 momentum and work to capitalize on the project's detailed implementation plan. Key Year 2 project plans include:

- Continuation of regular CLT and research theme meetings with quarterly all-team meetings and an annual project retreat scheduled for December 2020
- Develop additional survey instruments to collect data from other project constituencies (e.g., undergraduate students and external stakeholders)
- Conduct a formative strategic assessment site visit by a team of external experts organized by the project's external evaluator
- Form and implement the project's External Advisory Board (EAB), a Tri-Jurisdictional Institutional Advisory Board (IAB), and two project committees (Collaborative Research Committee; Mentoring, Education, & Engagement Committee)
- Organize and conduct an INSPIRES field trip to visit a research site, build team relations, and continue refinement of research objectives



- Continue project team recruitment with focus on undergraduate and graduate students, post-doctorate fellows, and early-career faculty members
- Conduct key stakeholder outreach events such as teacher workshops, site visits, and technical sessions
- Organize and conduct a short graduate student training session on a key project focal area that helps to build collaborations across themes and jurisdictions
- Develop a project mentoring strategy for early career faculty
- Determine and implement individual develop plans for project participants

Forest-based Research

The CRSF is home to a number of forest-based research programs. The **Cooperative Forestry Research Unit (CFRU)** serves the large, commercial forest landowners of Maine and has more than 30 members representing over 8 million acres of forestland. CFRU scientists conduct applied research that provides Maine's forest landowners, forestry community, and policymakers with the information needed to ensure both sustainable forestry practices and science-based forest policy. The **Center for Advanced Forestry Systems (CAFS)** is an NSF industry-university cooperative whose goal is to facilitate the connections between forestry research programs and industry members to solve complex, regional and national industry-wide problems. Phase 3 of CAFS kicked off in late 2019, with new projects focused on site carrying capacity, site productivity modeling, and remote sensing.

The **Northeastern States Research Cooperative (NSRC)** is a competitive grant program funded by the USDA Forest Service. Although funding for new projects was suspended from 2016 to 2019, working with the region's legislative delegations and interested stakeholders, the four state directors, along with the director of the Hubbard Brook Research Foundation, were able to gain renewed congressional funding to support cross-disciplinary, collaborative research in the Northern Forest in 2020.

In addition to these programs, the CRSF works cooperatively with scientists, foresters, and students to support research on three long-term research sites in Maine. **Holt Forest**, situated on 300 acres in Arrowsic and funded by Maine TREE Foundation and research grants, has been the site of a long-term pine-oak forest ecosystem study since 1983, collecting data on trees and regeneration, small mammals, and a variety of avian species. Research has been conducted at the site by a number of multi-disciplinary teams of scientists from the University of Maine's College of Natural Sciences, Forestry, and Agriculture since its inception. The **Howland Forest** is a continuously operating forest ecosystem research site established in 1986 by University of Maine researchers with the cooperation of International Paper. Studies at Howland Forest focus on nutrient cycling, forest ecology, ecosystem modeling, acid deposition, remote sensing, climate change, and carbon sequestration. The site welcomes research scientists from the University of Maine as well as institutions throughout the country and is home to various model and sensor development efforts. The **Penobscot Experimental Forest** is managed via a Joint Venture Agreement between the University of Maine and US Forest Service Northern Research Station. The PEF hosts long-term research conducted by USFS scientists, university researchers, and professional forest managers in Maine and provides the setting for forestry education and public outreach.

Cooperative Forestry Research Unit

The CFRU continues to deliver a wide array of relevant research findings that contribute to the sustainable management of Maine's working forests. In 2019, CFRU provided approximately $280,000 to help fund 17 different projects in our core interest areas. Additionally, for the FY19-20 fiscal year budget, the membership approved $250,000 in funding for 15 projects. Some of these projects are a continuation of multi-year research efforts while others are entirely new projects. These projects range from the continued development of CFRU's long-term adaptive silviculture network (MASN) to the habitat needs of species of special concern. In addition, CFRU was able to partner and help fund ongoing projects such as Spruce budworm L2 monitoring and statewide LiDAR data acquisition. In the fall of 2019, stakeholders were invited to join a field tour of four sites in western Maine that encompass the interface of forestry and wildlife habitat. Topics of the tour included riparian management, carnivore monitoring, deer habitat modeling from LiDAR, Bicknell's Thrush and Rusty Blackbird habitat use, and wind power development. The CFRU continues to provide critical leadership on key issues facing Maine's forestland managers in the region and country. The following project summarizes CFRU projects in three primary areas: silviculture and productivity, growth and yield modeling, and wildlife habitat. The CFRU 2019 Annual Report, including detailed project reports, are available on the CFRU website: **www.umaine.edu/cfru**.

Forest operations research. Photo courtesy Anil Kizha.

Silviculture and Productivity

Silviculture and Operations in Northern White-Cedar Lowlands

Year 2 of 3

LAURA KENEFIC (PI), ANIL RAJ KIZHA, SHAWN FRAVER, AMBER ROTH,
JAY WASON, AND KEITH KANOTI

Northern white-cedar occurs throughout central and northern Maine as a minor species in mixed stands and as a dominant species in lowlands. Though research over the last decade has addressed management of white-cedar in mixtures, there are still questions about management of lowlands. Such stands are important for commodity production and ecological values. This collaborative and interdisciplinary project is generating new findings related to silviculture, production, and ecology in a regionally important forest type, facilitating effective and active management by CFRU member organizations and others.

The harvest at the PEF removed 12 cords/acre of white-cedar and 4 cords/acre of other species. This reduced stocking of trees ≥6 inches dbh by about 36%. Photo courtesy L. Kenefic.

Key Findings

- In winter 2019, harvesting was completed on the Penobscot Experimental Forest. Delay-free cycle times and predictor variables were recorded for the processor and forwarder using detailed time-motion study techniques. Harvested wood timber volume was estimated from scaling data and scale tickets. Machine rate calculations to determine hourly production cost were made based on information from the forest management company.
- Harvesting is scheduled for winter 2020 and time-motion studies are planned for the Baskahegan site. Post-harvest measurements are planned for summer 2020.
- The scope of work was expanded in 2019 to provide additional information about white-cedar regeneration based on preliminary observations of the importance of microtopography (pits and mounds) for regeneration and growth in stands with seasonally high water table, and of the prevalence of regeneration by layering in lowland white-cedar stands.

Long-Term Impacts of Whole-Tree Harvesting: The Weymouth Point Study

Final Report

C.T. (TAT) SMITH, RUSSELL D. BRIGGS, JOHN L. CAMPBELL, IVAN FERNANDEZ, SHAWN FRAVER, BRIAN E. ROTH, INGE STUPAK

Research at Weymouth Point was designed to evaluate impacts on forest ecosystem nutrient (N, P, K, Ca and Mg) and carbon (C) pools of whole-tree harvesting (WTH) and stem-only harvesting (SOH) compared to an unharvested reference (REF) forest. REF and clearcut watersheds were sampled in 2016, 35 years after clearcutting in 1981. Living aboveground forest accumulated 70 Mg C ha^{-1} (60%) versus 116 Mg C ha^{-1} in the pre-harvest forest. The REF forest contained 16 Mg C ha^{-1} deadwood versus 5-7 Mg C ha^{-1} in WTH-SOH, and, correspondingly, 120 versus 112-136 Mg C ha^{-1} in mineral soil to 100 cm depth. Forest floor lost 10-26 Mg C ha^{-1} since clearcutting. Ecosystem C pools modelled with a carbon budget model (CBM-CFS3) overestimated dead organic matter C pools compared with empirical estimates; living biomass C was modelled accurately. These results may inform development sustainable forest management standards in northern New England.

Key Findings

- *Tree growth:* 35 years after WTH does not differ from tree growth after SOH, cf. also 2017 CFRU report. Site index estimates indicated Forest Vegetation Simulator Northeast Variant (FVS-NE) simulations of stand growth and yield should assume SI 50 for the Reference watershed plots and SI 65 for WTH and SOH treated plots.
- *Element concentrations in soil:* Concentrations of total C and N appear to be somewhat higher in harvested watershed soils (WTH and SOH treatments) than Reference watershed soils at 0–10 and 25–50 cm depths, but less Bray-P and exchangeable Ca.
- *Element concentrations in biomass:* N, P, K, Ca and Mg concentrations were generally higher or similar in tree biomass in the harvested watershed 35 years after harvest, compared to 1980 prior to harvest, indicating that soil nutrient availability has not been degraded. Balsam fir biomass generally had higher nutrient concentrations than red spruce.
- *Deadwood C:* Dead woody debris in the unharvested forest was about three times that observed in harvested watershed treatments.
- *Total Ecosystem C:* Managed stands recovered to about 79% of the pre-harvest forest C pool (Figure 13).

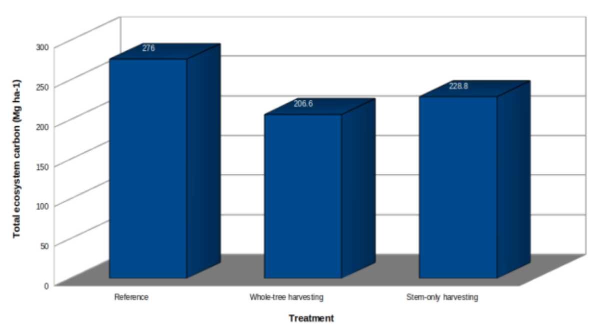


Figure 13. Total ecosystem carbon 35 years after harvesting.

Evaluating the Effects of Timber Harvesting Operations on Soil

Final Report

ANIL RAJ KIZHA (PI), BRIAN ROTH

This controlled field experiment was developed to examine the difference in operational cost and potential soil disturbance (compaction and rutting) between two ground-based timber harvesting scenarios. The second objective was to evaluate the residual stand damage following different partial timber harvest silvicultural prescriptions and harvesting methods. The best management practices (BMP) cost was calculated using two methods – as a percentage of the skidders' productive machine hour ($153.87 PMH^{-1}) devoted to BMP implementation and the cost per cubic meter of wood generated. In the residual stand damage study, bole wounds were the major form of damage. In terms of silvicultural prescription, higher intensity of harvest resulted in a larger amount of residual stand damage. The harvesting method also had a profound influence on the damages, with the hybrid cut-to-length (Hyb CTL) harvest inflicting lesser damage to residual trees compared to whole-tree harvest.

Key Findings / Accomplishments

- The average time dedicated for picking slash at the landing and handling slash ranged from 1.1–3.8 min and accounted for 7–32% of skidder's delay free cycle (DFC) time.
- The cost of implementing BMPs per cubic meter of wood produced ranged from $1.00–$3.70.
- The cost of BMP implementation was directly influenced by extant and the severity of the sensitive zone within the harvest zone, and less impacted by the skidding distance.
- BMP implementation can be incorporated into a mainstream harvesting operation without much affecting the economic feasibility.
- Other than the pressure exerted by machines, skidding direction and skid trail slope was also found to affect the bulk density and total porosity of the soil
- Moisture content of the soil plays an important role in aiding soil disturbance.
- The Hyb-CTL treatment had fewer wounds per ha and lower damage severity compared to whole-tree harvest.

Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies

Year 1 of 2

HAMISH GREIG (PI), AMANDA KLEMMER, ROBERT NORTHINGTON, SHAWN FRAVER, MINDY CRANDALL, AND ETHEL WILKERSON

Long-term costs and ecological benefits of alternative riparian buffer designs were measured to provide data that can be used to guide riparian management decisions. To achieve this goal, we first need to summarize the current state of knowledge of the investment cost and effectiveness of riparian buffers in the Northeast. Next, we plan to resample an existing CFRU-funded experiment to quantify the long-term (17-year) ecological outcomes and economic investment in alternative riparian buffer designs for forested freshwater resources.

Key Findings

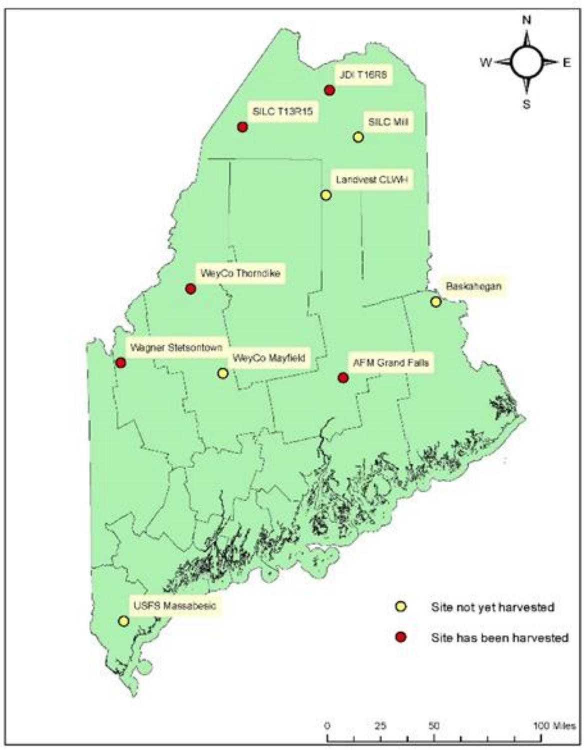
- Literature searches and synthesis conducted by our undergraduate collaborators will form the basis of our white paper, to be completed in the next funding year. In addition to generating products that contribute to specific research objectives, the partnership enhanced workforce development by training 16 undergraduate students in the economic and ecological aspects of riparian forest management. Students also practiced skills associated with the scientific process, from forming hypotheses and questions, to collecting and analyzing data, and written/oral communication of results.
- Data analyses of our fieldwork is being finalized, but initial results indicate that ecological communities reflect a legacy of riparian management approaches 17 years after initial harvest occurred. For example, invertebrate communities differed among riparian management treatments in the relative abundance of different insect species. Communities in control streams were distinct from those in harvested streams, and streams subject to partial harvest and clear cuts with no riparian buffers were the most different from unharvested controls. Streams with 11m and 23m buffers typically supported communities that were intermediate between control streams and those with 0m buffers.
- Although ecological communities differed among riparian management treatments, the total diversity (number of species per stream) and total abundance of insects in streams and adjacent riparian forests appeared robust to riparian harvest. Moreover, we observed consistent rates of leaf breakdown across different riparian management treatments, suggesting differences in ecological communities did not translate to impaired stream ecosystem function.

Maine's Adaptive Silviculture Network (MASN)

Year 3 of 5

AARON WEISKITTEL (PI), ANIL RAJ KIZHA, AMBER ROTH

This is the second year of a five-year project to establish a new region-wide study series: Maine's Adaptive Silviculture Network (MASN). The MASN study will be the backbone for new research in the areas of growth and yield, wildlife habitat, harvest productivity, regeneration dynamics, remote sensing of inventory, forest health, and others. There has been much interest from researchers wishing to take advantage of these study sites on research problems of interest to CFRU membership. In addition to the American Forest Management (AFM) installation established at Grand Falls township (TWP) in the summer of 2017, there have been two additional installations established in 2018: T16 R8 on Irving Woodlands, LLC and T13 R15 on Seven Islands Land Company. Three more installations are laid out and harvests planned for 2019: Stetsontown TWP on Wagner Forest Management, Thorndike TWP on Weyerhaeuser Company, and the Massabesic Experimental Forest of the U.S. Forest Service (USFS) Northern Research Station.



2019 MASN Site Locations

Key Findings/Accomplishments

- Baseline protocols have been documented and preliminary data collected on forest birds, inventory, understory vegetation, harvest damage, and 360-degree photo documentation.
- 8 basal area summaries for the sites that had been inventoried in 2019.
- The files for Stetsontown, T13R15 and Thorndike have good comparisons for pre/post basal area summaries around a harvest.
- The files for SILC Mill, Mayfield, CLWH and Baskahegan were the 2019 installations and so no post-harvest data is available yet.

Growth & Yield Modeling

Assessing and Monitoring Soil Productivity, Carbon Storage, and Conservation on the *Maine Adaptive Silviculture Experimental Network (MASN)*

Year 1 of 3

JOSHUA PUHLICK (PI), MARIE-CÉCILE GRUSELLE, IVAN FERNANDEZ, BRIAN ROTH

The main objective of this project is to evaluate the influence of different forest management practices on soil productivity, carbon (C) storage, and conservation across operational-scale research installations in Maine. We will identify forest management practices and soil properties that: (1) promote adequate nutrient availability that supports forest sustainability, (2) maintain or enhance soil C stocks, and (3) minimize compaction and erosion. This will provide CFRU members with information related to soils during third-party audits of compliance to SFI, Outcome Based Forestry, and similar programs.

Key Accomplishments

- In 2018 and 2019 (before and after timber harvesting), soils were collected in northern hardwood stands. The soils series of the study areas fall within the Chesuncook (the Maine state soil) catena. The study areas support a diverse range of species including sugar maple, red maple, yellow birch, American beech, spruces, and balsam fir. The forest management practices that will evaluated for their influence on soils include irregular shelterwood cutting, crop tree release, partial harvesting, and control (no cutting in 2018).
- Soil samples from 52 quantitative soil pits and 150 organic horizons were collected over both years. 550 soil samples were collected to determine mineral soil bulk density for evaluating soil compaction after harvesting. The installations were harvested from mid to late summer of 2018. Live and standing dead trees as well as downed woody debris were measured in association with quantitative soil pit locations.
- In 2020, an additional MASN installation in northern Maine between Ashland and Portage Lake will be sampled.

Development of Individual-Tree and Stand-Level Approaches for Predicting Hardwood Mortality and Growth Response to Forest Management Treatments in Mixed-Species Forests of Northeastern North America

Final Report

JOSHUA J. PUHLICK (PI), CHRISTIAN KUEHNE

In year two of this two-year project, we used repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation Study and the Silvicultural Intensity and Species Composition (SIComp) experiment to evaluate hardwood growth response to forest management treatments. These data will also be used to develop growth and mortality response functions for common hardwood species of the northeast North America to account for treatment effects after various forest management activities.

Key Findings

- The Rehabilitation Study measurements were used in analysis of crop tree growth and quality in cutover mixed-wood stands after rehabilitation treatments. A manuscript with the results of this analysis were published in a peer-reviewed journal.
- Analysis of the SIComp experiment data were divided into two parts: (1) the evaluation of common softwood and hardwood species response to precommercial management activities, and (2) assessing improved white spruce and hybrid poplar crop tree growth over time as well as individual crop tree and stand metrics 14 years after planting. The results of the SIComp analyses were presented in a Center for Advanced Forestry Systems report.

- The measurements and findings from both studies will be used to develop tree growth and yield models for early successional hardwood and mixed-wood stands.

Developing a Refined Forest Site Productivity Map for Maine and New Brunswick by Linking Biomass Growth Index to Remotely Sensed Variables

Final Report

PARINAZ RAHIMZADEH-BAJGIRAN (PI), AARON WEISKITTEL, CHRIS HENNIGAR

Due to the essential need for a fine-resolution region-wide map of forest productivity for effective large-scale forestry planning and management, a novel productivity model, biomass growth index (BGI), was suggested by Hennigar et al.[2] for the Acadian region. Given the strong potential for the improvement of this model by incorporating remote sensing (RS) data, several newly-launched Sentinel-2 satellite derived variables were selected for the analysis: 21 variables including 9 single spectral bands and 12 spectral vegetation indices (SVIs) with a combination of other variables were used to predict tree volume/ha (GTV) and tree height. Four Sentinel-2 variables were selected for biomass growth prediction in Maine and New Brunswick using 7,738 provincial permanent sample plots. Among four best variables, S2REP was selected to produce BGI. v2 for Maine and New Brunswick due to its highly significant performance in predicting BGI. S2REP was identified as the most important variable over others to have known influence on site productivity.

Key Findings / Accomplishments

- Results showed a 10-12 % increase in out of bag (OOB) r^2 when Sentinel-2 data were included in the prediction of total volume. Prediction of stand-level volume based on age, species composition, management type, and BGI yielded an OOB r^2 of 68%, whereas the addition of the Sentinel-2 data increased the OOB r^2 to 80.5%. Additionally, dropping species composition as a predictor variable did not significantly affect the OOB r^2 (80% vs. 78%).
- After reviewing the correlation matrix of the bands and indices, green and NIR bands, S2REP and NDVI45 were selected as the best bands and indices.
- Prediction of total volume (GTV), with spectral bands and indices performed the best when two single bands (green and NIR) and two SVIs (S2REP and NDVI45) were used.
- BGI does not seem to have considerable effects on predicting GTV. Results for height prediction incorporating Sentinal-2 data were similar to those obtained for GTV.
- S2REP was identified as the most important variable over others (including site variables and Sentinel-2 variable) to have known influence on site productivity.
- Green band and NDVI45 were not well correlated with plot growth rate.

[2]Hennigar, C., Weiskittel, A.R., Allen, H.L., MacLean, D.A., 2016. Development and evaluation of a biomass increment-based index for site productivity. Canadian Journal of Forest Research, 10.1139/cjfr-2016-0330

- While only a slight improvement in accuracy of the model occurred (around 2%), substantial changes to coefficients of other variables were evident; i.e., some site variables became less important when S2REP was included.
- When BGI v2 was mapped for all of Maine and New Brunswick (Figure 14), some regional difference was evident, but locally there were more visually striking changes in good vs poor sites. The S2REP incorporated BGI maps clearly predict poorer site productivity in areas of exposed rock in the NB highlands, compared to the previous BGI map.

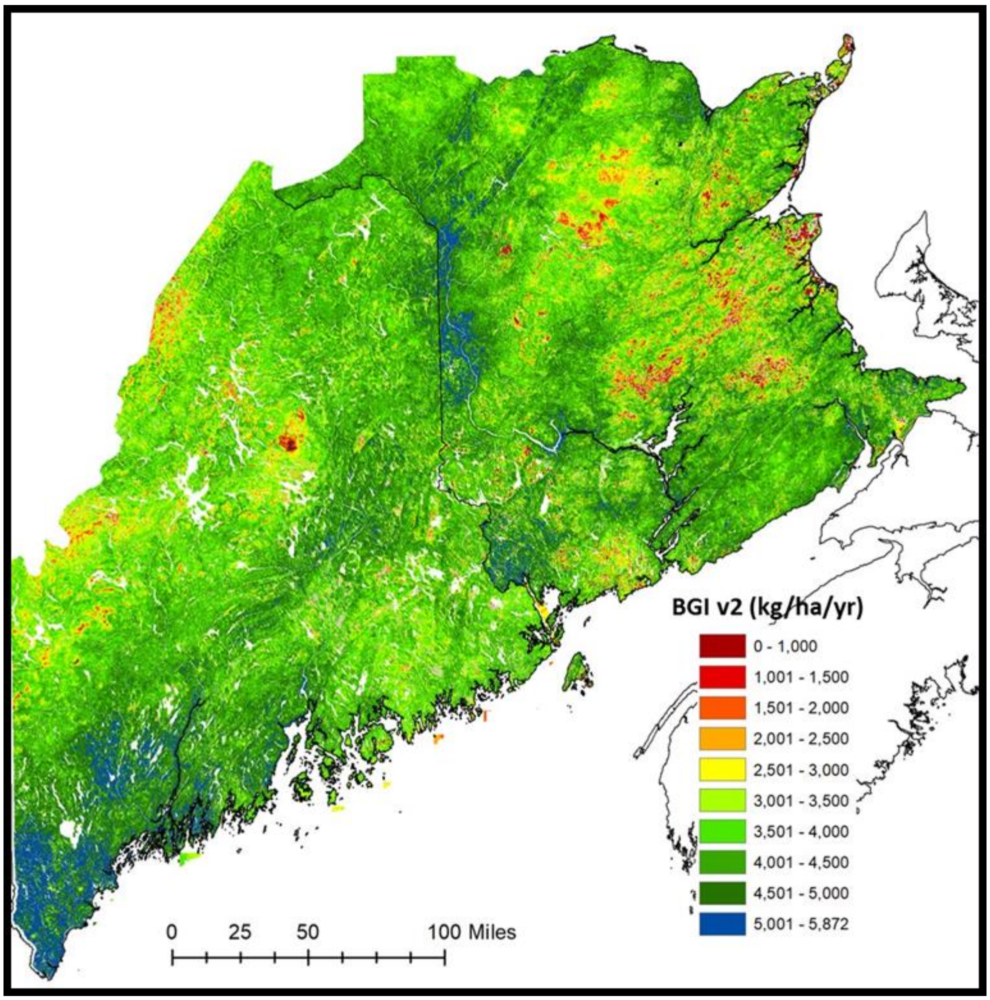


Figure 14. New Biomass Growth Index map for Maine and New Brunswick. Available online at http://bit.ly/BGImap.

Measurements, Models and Maps: Toward a Reliable and Cost-Effective Workflow for Large-Area Forest Inventory from Airborne LiDAR Data

Year 1 of 3

DANIEL HAYES (PI), DAVID SANDILANDS, ANTHONY GUAY, AARON WEISKITTEL

In its first year, this project has organized and carried out initial investigations into the use of LiDAR remote sensing analysis to enhance the design and operation of inventory programs for Maine's forest industry stakeholders. The research conducted here is evaluating ground-based inventory plot designs together with existing, publicly available Airborne Laser Scanning (ALS) data sets processed in a high-performance computing environment for workflow efficacy in generating geospatial data products useful for forest management. For these initial investigations, we have partnered with the Seven Islands Land Company in using their Ashland West property (~150,000 acres) to evaluate the impact of plot type, size and location accuracy on model prediction of forest inventory attributes derived from relating field data sampling with wall-to-wall LiDAR measurements across the study area. Our initial results have highlighted some of the challenges in linking plot data with the LiDAR models – particularly with variable radius plots with large locational error – but also suggest opportunities to improve results with alternative plot designs and ALS data sets that will be the focus of investigations over the second year of this project.

Key Findings / Accomplishments

- A comprehensive, flexible and efficient workflow was developed for building, applying and evaluating EFI prediction maps using an area-based approach.
- In testing several alternative calibration data sets, model performance showed significant improvement when built on a newer set of plot data located with high-accuracy (survey-grade) GPS as compared to older data collected with a lower-accuracy (navigation-grade) system. The modeling also demonstrated the importance of consistency with scaling and summary calculations in the plot data for reducing error in the LiDAR-based models.
- Volume predictions were also compared to an advanced artificial intelligence-based method by species composition, which showed our randomForest-based method performed better.
- Wall-to-wall EFI maps of percent softwood, stem density, quadratic mean diameter, basal area and volume were generated for the entire Ashland West study area.
- Visual evaluation of the EFI maps suggest broad agreement in spatial patterns with basemap imagery as well as a regional-scale LiDAR data product developed using artificial intelligence. The predictions from the locally calibrated models generally showed better agreement with observations in this study area than the regionally developed products.

- In collaboration with CFRU members, the Wheatland Geospatial Lab (WGL) organized and carried out several outreach events and technical workshops related to project research involving the use of LiDAR in forest inventory and management, including terrain and hydrologic modeling and wet areas mapping workshops and a joint CRSF/WGL exhibit at the 2019 New England Society of American Foresters meeting in Burlington, VT.

Cartographic Depth-to-Water Mapping for Maine, Using Existing and Forthcoming LiDAR-DEM Coverage

Year 1 of 2

PAUL A. ARP (PI)

The project involved presenting the current state of University of New Brunswick's LiDAR-based flow-channel, depression and wet-areas mapping initiative through presentations and rollout workshops, by focusing on select proof-of-concept sites. The purpose of these presentations and workshops was to inform how geomorphic features such as flow channels, depressions, cartographic depth-to-water and related seasonal variations can be emulated based on digital elevation models (1 m resolution).

Key Findings / Accomplishments

- Presentations and workshops on LiDAR- and UAV-based flow-channel, depression and depth-to-water presented in Orono, Bangor, Presque Isle, Augusta and Bingham. In addition, several field excursions were also conducted.
- Mapping results generally coincide with GPS-tracked streams, wetland borders, depressions, and road-stream crossing locations, within meters.
- Soil trafficability depends on topographic location, weather and soil substrate. LiDAR-generated trafficability maps can be produced when soils are saturated, at field capacity, and when the soils are at, say, one third of field capacity.

Spruce Budworm Population Monitoring: L2 Surveys

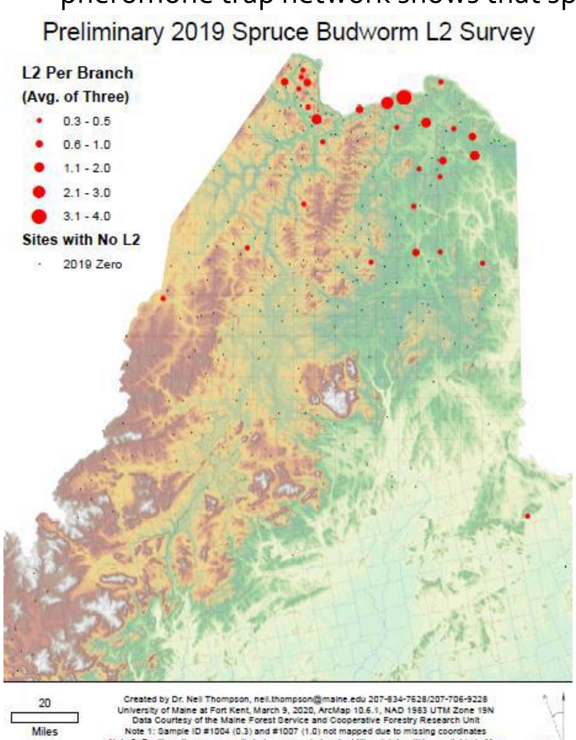
Year 3

BRIAN ROTH (PI), ERIN SIMONS-LEGAARD, KASEY LEGAARD

Sampling the second instar (L2) larval population of spruce budworm can identify areas of local population growth (versus immigration) and help managers anticipate the degree of defoliation to be expected during the next growing season. Although there is generally thought to be a positive relationship between pheromone trap catch and larval abundance, the strength of that relationship is likely to vary in space and time. In Maine and New Brunswick, L2 counts have so far been highly variable in areas with high moth trap catch and overall rates of L2 occurrence across plots have been relatively low. This project aims to collect data on pheromone trap catch and larval abundance in northern Maine ahead of the next outbreak. (Maps of L2 survey results are available at the Spruce Budworm Maine website: https://www.sprucebudwormmaine.org/map/l2-survey-maps.)

Key Findings/Accomplishments

- Spruce budworm populations in Maine have left the "stable" phase and appear to be building. Pheromone and light trap catches have been up above zero for a number of years, defoliation in Quebec has increased year after year, and defoliation has been mapped in New Brunswick.
- A total of 385 usable pheromone trap samples were collected in 2019 and the expanded pheromone trap network shows that spruce budworm is widespread, and that average trap catch has increased substantially from 2018 (Maine Forest Service SBW in Maine report, 2019).



- Defoliation was assessed by CFRU student employees on all L2 sites.
- Just under six percent of sites were positive in 2018, with a combined total of 25 larvae recovered from 17 of 290 sites. Just over 10 percent of sites were positive in 2019, with a combined total of 70 larvae recovered from 30 of 271 sites (see map of preliminary results).
- The maximum average larvae per branch increased from 1.3 in 2018 to four in 2019.
- CFRU cooperators continue to facilitate the study by placing pheromone traps and collecting branches for the L2 study.

Wildlife Habitat

Responses of Marten Populations to 30 Years of Habitat Change in Commercially Managed Landscapes of Northern Maine

Year 2 of 3

DANIEL HARRISON (PI), ERIN SIMONS-LEGAARD

We resurveyed commercially managed timberlands bordering the western boundary of Baxter State Park for American marten in 2018 and 2019 by replicating leaf-on season trapping and radio-tracking protocols established from 1989–1997. Despite consistent spatial and temporal trapping effort over time, capture rates of resident marten varied among and within distinct study eras. During the current study period, we documented the lowest capture rate of annual residents and most male-biased sex ratio of any year of study. Male martens typically reach breeding age (≥ 1yr) a year prior to females (≥ 2 yrs). Ground telemetry efforts in 2018 and 2019 yielded 964 locations, contributing to an overall dataset of 7,009 telemetry locations on 153 resident marten. Future work will integrate these data with a time series of habitat data developed from satellite and aerial imagery to investigate marten responses to three decades of habitat change.

Key Findings / Accomplishments

- Despite consistent spatial and temporal trapping effort over time, capture rates varied considerably among and within the three study periods (Figure 15).
- We observed higher interannual variability in resident marten captures during the 2018–2019 interval than during previous years of study. In 2019 we captured 3.5-fold more resident marten than in 2018, whereas trapping results were more consistent across consecutive years during the earlier phases of the study (1989–1997).
- Our live-trapping results suggest lower representation of non-resident martens (i.e., martens that did not establish home ranges within our study area) relative to resident martens in 2018 and 2019 than in previous years of study. On average, our 2018–2019 live-trapping resulted in the lowest ratio of total individuals captured relative to captures of individuals subsequently documented as residents (1.2 total individuals captured per resident, compared with 1.5 individuals captured per resident during 1994–1997 and 1.7 individuals captured per resident during 1989–1990). Fewer non-resident captures during the current study period compared with prior years of study may simply reflect changes in local habitat availability and density. Alternatively, fewer non-resident captures could be indicative of a broader-scale population decline since the 1990s.

- The sex ratios (M:F) of resident martens we observed in 2018 and 2019 were heavily skewed towards males, as compared to sex ratios that did not differ significantly from 1:1 during the 1989–1990 or 1994–1997 study periods. Male martens typically reach breeding age (≥ 1yr) a year prior to females (≥ 2 yrs). Male-biased sex ratios in the current study period may indicate broader demographic changes since the 1990s, including changes in effective population sizes.
- Our ground telemetry efforts in 2019 yielded 753 locations (mean error ellipse = 0.9 ± 1.1 hectares) on 20 resident martens in T4 R11 and T5 R11 WELS. Pooled with prior years, our working dataset is comprised of 7,009 individual locations on 153 resident marten, with a mean of 45 ± 7 locations per animal.

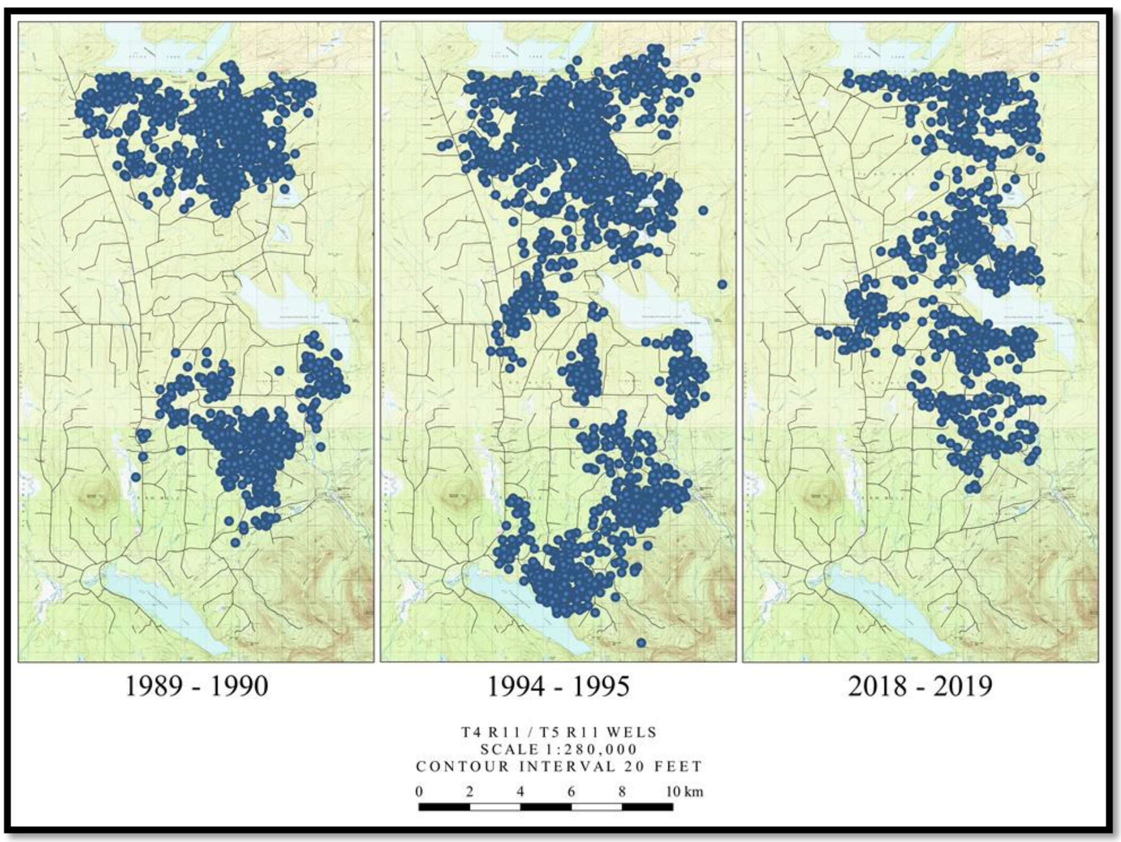


Figure 105. Distribution of initial captures and telemetry locations for resident, nonjuvenile (≥ 1 yr) American marten monitored during the leaf-on season (approximately 15 May – 31 October) in T4 R11 and T5 R11 WELS during 1989–2019. We pooled locations across consecutive two-year intervals to depict three distinct eras of study: 1989–1990, 1994–1995, and 2018–2019.

Rusty Blackbird Use of Commercial Spruce-Fir Forests in Northern New England

Year 1 of 2

AMBER ROTH (PI), CAROL FOSS, ADRIENNE LEPPOLD

The Rusty Blackbird (*Euphagus carolinus*) is a spruce-fir obligate that has experienced a steep population decline since the 1970s. How the species reacts to intensive commercial forestry practices within their breeding range have yet to be assessed. Our research seeks to evaluate Rusty Blackbird nesting and fledgling habitat selection and survival in intensively managed forests in Maine and New Hampshire that contain practices such as pre-commercial thinning and regenerating clearcuts. Through the use of radio telemetry, GIS, and habitat measurements, we have begun to describe how the species is using these commercial landscapes. Birds during the 2019 field season were confirmed nesting in wetlands, naturally regenerating stands, and stands that had undergone pre-commercial thinning. A second field season is planned for summer 2020 which will incorporate state LIDAR data to describe habitat characteristics. This research will be used to revise management guidelines for the species.

Key Findings / Accomplishments

- 23 nests were found in New Hampshire and 9 in Maine.
- Rusty Blackbirds (see photo) were confirmed nesting in naturally regenerating clearcut stands, stands that underwent pre-commercial thinning, and wetlands.
- VHF-radio transmitters were deployed on 10 nestlings from six nests in Maine, and on 10 nestlings from six nests in New Hampshire.

Rusty Blackbird nestlings affixed with VHF radio transmitters. Photo courtesy Amber Roth.

Bicknell's Thrush Distribution and Habitat Use on Commercial Forests in Maine

Final Report

KAITLYN WILSON (PI), AMBER ROTH, HATEYA LEVESQUE

Bicknell's thrush (BITH) is a range-restricted habitat specialist occurring in balsam fir-dominated montane forests that have been recently disturbed and are undergoing successional growth or regeneration. The species historically occurs at elevations above 800 m in the U.S., but if suitable habitat is available, BITH can occur at lower elevations. The potential for suitable habitat at lower elevations exists in Maine because of the state's unique distribution of tree communities and due to changes in forest structure and composition brought about by forestry practices. By means of telemetry, resource selection functions, and LiDAR, we aim to understand the use of breeding habitat for BITH in commercial forestlands in Maine. To accomplish this, we successfully tracked 24 individuals to obtain 27 home ranges among the 2018 and 2019 breeding seasons at two study sites (see photo): Kibby Mountain (harvested landscape; 15 home ranges) and Mt. Redington (non-harvested landscape; 12 home ranges). Habitat selection analysis is underway.

Key Findings / Accomplishments

- Home ranges averaged 21 ± 25 ha with a range of 2.5 ha – 129 ha. The largest home range was that of a second-year male who made multiple long trips outside of his core home range area. On average, home ranges were approximately twice as large at Mt. Redington (29 ha) compared to those at Kibby Mountain (14 ha).
- Habitat was quantified using LiDAR data and includes estimates of canopy cover at multiple height cut-offs (1.5m, 2.0m, 2.5m, and 3.0m), tree counts for small (<10cm diameter) and large (>10cm diameter) trees, biomass estimates for small and large trees, canopy height, canopy roughness, and disturbance metrics (year of last, magnitude, and duration). Additionally, forest composition was categorized using a combination of datasets including NLCD, inventory data, LiDAR, and Google Earth.

Bicknell's thrush habitat. TOP LEFT and TOP RIGHT: Traditional high elevation habitat (above 800 m) at Mt. Redington (left) and Kibby Mountain (right). BOTTOM: Commercially managed spruce/fir stand at Kibby Mountain (below 800 m). Photos courtesy Kaitlyn Wilson.

Development of Large-scale Optimal Monitoring Protocols for Carnivores in Maine

Year 2 of 3

Alessio Mortelliti, Bryn Evans

Our project began in early 2017 with a pilot season (three study areas) and has since expanded to full-scale surveys (31 study areas to date) in summer and winter seasons from 2017 to 2021. We conduct trail camera surveys for carnivore species in areas across the state selected to assess the variation in occupancy probabilities between different forest stand types and ages, harvest histories, landscape configuration, latitudes, and other anthropogenic influences. During the second year of CFRU funding (October 2018 to September 2019) we a) completed our second year of full-scale surveys (88 points during winter months), b) initiated our third year of surveys (59 revisited sites and 38 new sites), and c) published the first peer-reviewed article from this project.

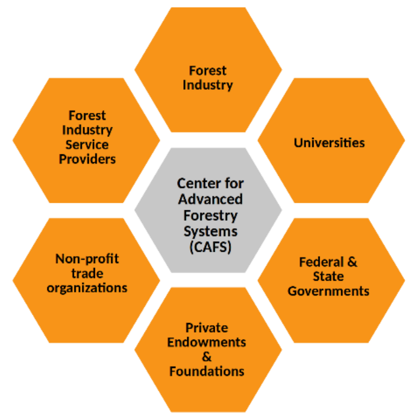
Key Findings / Accomplishments

- A notable accomplishment within the time frame of CFRU research year two was the publication of our first peer reviewed article from this project (https://doi.org/10.1371/journal.pone.0217543). We conducted multi-method occupancy analyses (Nichols et al. 2008) on the data from our pilot season to compare the detection success of 1, 2 or 3 trail camera units spaced either 100 m or 150 m apart in linear transects. We used the results from analyzing detection histories of six species (marten, fisher, coyote, white-tailed deer, snowshoe hare and American red squirrel) to finalize our study design.
- In 2019 we surveyed at 59 "permanent" survey location in both winter and summer, as well as completing winter surveys for 24 new sites representing intermediate harvest and adding 28 new locations for fur harvest in summer.
- To date, we have "tagged" to species and cleaned data from roughly 130,000 trail camera images with the assistance of undergraduate research assistants and volunteers.

Lynx strolling by survey location, captured by game camera.

Center for Advanced Forestry Systems

The **Center for Advanced Forestry Systems (CAFS)** is an Industry/University Cooperative Research Center (I/UCRC) program funded by the National Science Foundation (NSF) in partnership with CFRU members. CAFS is a multi-university center that unites university forestry programs with forest industry members across the United States to solve forestry problems using multi-faceted approaches and questions at multiple scales, including molecular, cellular, individual tree, stand, and ecosystem levels. Collaboration among scientists with expertise in biological sciences (biotechnology, genomics, ecology, physiology, and soils) and management (silviculture, bioinformatics, modeling, remote sensing, and spatial analysis) is at the core of CAFS research.



In late 2019, UMaine's CRSF successfully led six other universities in gaining funding from NSF for Phase III of CAFS, which has awarded each site $60,000 per year (each site must also have a minimum of $350,000 per year from industry members to support the work of each site). Phase III plans include greater integration of research efforts and a more nationally relevant focus within four primary research areas: forest management, forest genetics, decision-support tools, and remote sensing.

Like so many people and plans affected by the global Covid-19 pandemic, CAFS researchers had to pivot and adapt to move their projects forward. The annual in-person Internal Advisory Board meeting scheduled to occur in Washington State was re-formatted and held virtually in June 2020. Research leaders presented updates on 2 completed and 9 ongoing projects, and 3 new projects were proposed and accepted. Topics of current research include: improving white pine seedling survival, stand and tree responses to late rotation fertilization, assessing and mapping regional variation in potential site productivity and site carrying capacity, evaluation of machine learning algorithms for mapping tree species distribution, environmental predictors of form and quality in loblolly pine, using hyperspectral imaging to evaluate forest health risk, and a global study of long-term soil productivity experiments. New projects will focus on stand response to thinning, using predictive analytics to decompose site index, and physiological response to commercial fertilization programs in Pacific Northwest forest plantations.

To learn more about CAFS, and to access a pdf of the CAFS Phase 2 final report, visit **crsf.umaine.edu/forest-research/cafs/**

CAFS Summary 2020 Project Progress Reports

CAFS member sites are: University of Maine (UM; lead site), North Carolina State University (NCSU), Oregon State University (OSU), Purdue University (PU), University of Georgia (UGA), University of Idaho (UI), and University of Washington (UW).

Improving White Pine Seedling Survival by Combining Blister Rust Resistance with Defense-enhancing Endophytes

George Newcombe (UI), Marc L. Rust (UI), Mary Frances Mahalovich (USDA Forest Service), Greg Adams (J.D. Irving), David Miller (Carleton University), Brian Roth (UM), Mark Coleman (UI)

Western white pine (WWP) is among the most productive and valuable species on moist sites in the inland Northwest. However, an exotic fungal disease, white pine blister rust (WPBR), has devastated natural populations of WWP since its introduction in the early 1920s. The objective of this project is to compare WPBR resistance of selected WWP seed sources that are either inoculated or not inoculated with promising endophytes. After inoculation with endophytes and then with rust in September 2018 seedlings were to be evaluated for the first time for rust symptoms and signs in 2019 in the CDA Nursery. However, it was apparent in 2019 that the 2018 rust inoculation had failed; susceptible, endophyte-free controls should have had signs and symptoms at the very least but they did not. All endophyte treatments of the susceptible seed lot were re-inoculated in the field with rust in September 2019, and we will evaluate them in the 2020 growing season in the nursery and score them for WPBR resistance traits so more results are still to come.

Assessing & Mapping Regional Variation in Site Productivity

Rachel Cook (NCSU), Aaron Weiskittel(UM), Jeff Hatten (OSU), Cristian Montes (UGA), Mark Coleman (UI), Doug Jacobs (Purdue), Mark Kimsey (UI), Doug Maguire (OSU), Kim Littke (UW)

Precision forestry is based on the concept of optimizing the best management practices on each acre of ground. One of the primary determinants of optimal management practices is the potential site productivity, which influences the growth and development of forests. However, multiple metrics of potential site productivity are used by the forest industry with an unclear understanding of their primary differences and how they might vary across regions. Potential site productivity is generally assessed using site index or the dominant height at specified age, which is known to have several limitations and is difficult to assess across the landscape due to high measurement error potential and inherent variability. Soil characteristics that limit productivity vary across sites and require an in-depth understanding of resource availability to predict the likelihood of response to a given input. Identification of areas of current low productivity, as measured by leaf area or other biologically-based metrics, that have the greatest potential for improvement, as indicated by potential site productivity, can focus our efforts on managing stands with the greatest potential gains. This project will require cross-site collaboration and sharing of data of remotely sensed and empirical field data for spatial modeling of potential site productivity. The primary objective of this project is to develop a consistent and biologically-meaningful metric of potential site productivity that can be related to a combination of environmental and edaphic factors and mapped across the various regions.

Data gathering and compilation and forest soil classification mapping have started. We are currently working on a harmonized dataset for assessing regional variation in site productivity, a developed methodology for quantifying site productivity, compiling high-resolution raster layers of key site-level environmental variables as well as the predicted site productivity metric, and equations for deriving these various attributes.

INTERN: Gains from Advanced Genetics Western Larch across the Inland Northwestern United States

CEN CHEN (UI), ANDREW NELSON (UI), AND MARK COLEMAN (UI)

The current study utilized annual measurements of over 15,000 seedlings beginning immediately after planting to evaluate growth and mortality of planted interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mayr] Franco) and western larch (*Larix occidentalis* Nutt.) seedlings in northern Idaho and eastern Oregon for the first two years. These two species were selected since they are the most widely planted species in the region. Specific objectives of this study were to: 1) assess the effects of various factors (see next paragraph) on pre-establishment growth and mortality of planted interior Douglas-fir and western larch seedlings; 2) predict pre-establishment seedling growth and mortality using significant and influential factors from the assessment; and 3) compare specific differences between Douglas-fir and western larch and provide specific management suggestions.

Data include geographically referenced measurements of individual seedlings and vegetation cover surrounding each seedling, which enabled assessment of factors commonly considered influential on seedling growth and mortality, e.g., morphological attributes like height, root collar diameter, containerized rooting volume, and RGP, as well as site conditions and competition. Available site factors include topography, soil parent material, volcanic ash depth, and weather conditions. In addition, nursery and seedlot origin of seedlings was also available, including whether seeds were wild collected or from seed orchards and thus genetically improved for growth potential.

In the first year, diameter and height had larger effects on mortality of western larch, which generally was slimmer and taller than Douglas-fir, while survival of Douglas-fir was more sensitive to weather conditions. Scale of the effects of various variables on mortality became highly similar in the second year between the two species. Seedling mortality varied greatly across nurseries and seedlots. Precipitation, as well as initial diameter and height, were the most influential predictors of growth.

Environmental Predictors of Form and Quality in Loblolly Pine

CRISTIAN R. MONTES (UG), JOSEPH DAHLEN (UG), AND BRONSON BULLOCK (UG)

The project aims at developing a cost-effective methodology to assess stem quality using ground based mobile LiDAR technology to reduce sampling cost while increasing the amount of information captured at the time of an inventory. Based on the hypothesis that defects (forking, rust and ramicorn presence) can be spatially identified with a correlation to auxiliary variables like water deficit, excess water and soil physical properties, objectives are to describe stem defects using ground-based LiDAR by means of a data assimilation algorithm and to correlate defect with environmental variables (soil particle size distribution, water deficit and excess water) to determine spatially explicit defect models. In the past, assessments like this were only possible with a portable LiDAR instrument. The mobile LiDAR provides much more flexibility, at the cost of a noisier dataset. Specialized algorithms of data assimilation will allow for a better location of diameters and defects along the tree.

Analysis of Aboveground Nutrient Biomass on LTSP Sites Due to the Effects of Site, Harvest Removals, Weed Control, and Compaction

KIM LITTKE (UW), ERIC TURNBLOM (UW), AND ROB HARRISON (UW)

The objectives for this project are to examine aboveground biomass and nutrients on four long-term soil productivity (LTSP) sites, compare biomass allocation equations to previously established biomass allocation equations, understand the nutrient holding capacity of understory species due to treatments on each LTSP site, and compare the previous results of treatments on belowground nutrient biomass to aboveground nutrient biomass. Overstory and understory biomass sampling at the four sites have been completed. Separate biomass allocation equations have been developed for 5-year and 5-50-year regional Douglas-fir using standard tree measurements. This research provides key information on the short- and long-term changes in soil and site productivity due to intensive forest practices, leading to improved understanding of nutrient dynamics following organic removal, vegetation control, and compaction over the short- and long-term. Knowledge of how these factors interact will lead to better timing and application of chemical nutrients and/or vegetation control measures.

Stand and Tree Responses to Late-Rotation Fertilization

ERIC TURNBLOM (UW), KIM LITTKE (UW), JASON CROSS (UW), MASON PATTERSON (UW), AND ROB HARRISON (UW)

The study is designed to estimate a regional nitrogen fertilization response (RRE) for Douglas-fir on late-rotation stands. Specifically, objectives are to (1) determine the average, area-based volume response to late-rotation fertilization in stands being considered by landowners for fertilization; (2) estimate the regional economic returns to late-rotation fertilization investments; (3) validate the site-specific responsiveness predictions of the current model developed from the Stand Management Cooperative and CAFS Paired-tree Fertilization study; and (4) assess the ability to predict late-rotation response to fertilization across the Pacific Northwest according to PRS probes and available and total soil nutrition. Thus far, 38 installations have been installed, measured, and treated. Pretreatment soils have been analyzed on all installations. Next steps are to examine how aboveground and belowground nutrient allocation affect fertilizer response and compare site-specific response in the younger tree-based paired-tree and older plot-based late-rotation studies. When completed, this study will provide a much-needed examination of the economics involved with late-rotation fertilization and provide an average area-based volume response that will be used in growth models in six distinct regions.

Assessing and Mapping Regional Variation in Potential Site Carrying Capacity

MARK COLEMAN (UI), MARK KIMSEY (UI), CRISTIAN MONTES (UGA), RACHEL COOK (NCSU), AARON WEISKITTEL (UM), DOUGLAS MCGUIRE (OSU)

The objective of this research project is to (1) synthesize a nationwide forest measurements database from publicly available data and from CAFS members, (2) standardizing maximum carrying capacity modeling, to (3) provide regionally relevant, national forest carrying capacity models. Currently, database acquisition is occurring for the Northwest and portions of the Northern Rockies, soon to be expanded to other regions. Determination of optimal planting or thinning residual densities are an important management decision that influences stand development and final value. An improved understanding of forest carrying capacity variation and the ability to predict it at rather high spatial resolutions will help refine future stand management.

FOR/Maine

Strong forest. Strong economy. Strong communities.

The Forest Opportunity Roadmap/Maine (FOR/Maine) is a unique cross-sector collaboration between industry, communities, government, education, and nonprofits, which have come together to realize the next generation of Maine's forest economy. The coalition was created with support from the U.S. Economic Development Agency and U.S. Dept. of Agriculture to assess Maine's current industry, assets, and readiness, and to determine a strategy to capitalize on new opportunities. The CRSF is an integral part of this effort, leading committees focused on the forest industry sector and wood supply.

During Phase I, global wood products that can be competitively made in Maine were identified. Maine has a number of competitive advantages, including a plentiful supply of moderately priced softwood raw material, available in an area with existing harvesting and logistics infrastructure. Phase II of the project focuses on sustained collaboration for implementation of the Forest Opportunity Roadmap (Figure 16).

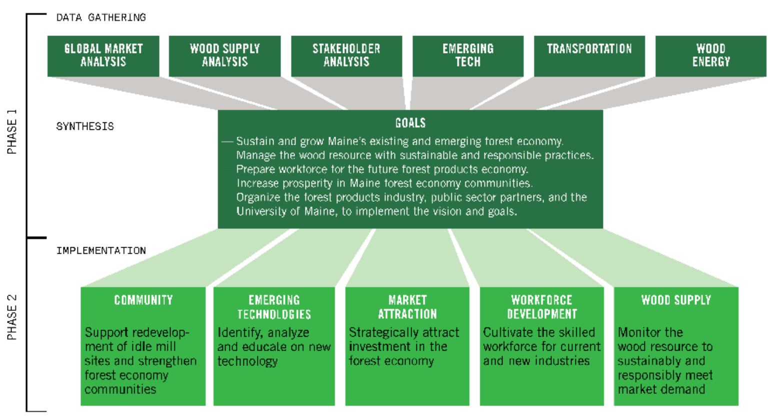


Figure 16. FOR/Maine phased implementation plan. Chart from formaine.org

As we continue to model and update our sustainable wood supply projections, we are moving forward to commercialize new uses of wood and place Maine as a global center of wood technology innovation; we are developing a marketing plan to bring more capital investments to Maine; and building a communications strategy to promote career opportunities in a resurging forest industry.

FOR/Maine's success is defined by its collective ability to adapt to market opportunities and build resilient rural communities and a strong workforce, while constantly focusing on an economic development strategy that retains existing businesses, promotes innovation, encourages investment and builds market diversity. Together, we are realizing the next generation of Maine's great forest economy.

For more information on FOR/Maine, visit their website at www.formaine.org.

Northeastern States Research Cooperative

The **Northeastern States Research Cooperative** (NSRC) is jointly directed through the USDA Forest Service, Northern Research Station, and a designated institution in each of the four Northern Forest states: the Rubenstein School of Environment and Natural Resources at the University of Vermont, the University of New Hampshire in cooperation with the Hubbard Brook Research Foundation (HBRF) in New Hampshire, the Center for Research on Sustainable Forests at the University of Maine, and the State University of New York College of Environmental Science and Forestry.

Since its inception in 2001, NSRC has been a critically important source of funding for applied forest research and outreach efforts throughout the Northern Forest. In 2017, after 16 years and nearly $25 million in research funding, the US Forest Service funding for new NSRC projects was suspended due to federal budget cuts. In response, the NSRC directors and Hubbard Brook Research Foundation sought input from business, industry, agency and community leaders to re-define and revitalize a new NSRC with a research agenda to improve the health of the Northern Forest environment and economy. Strongly supported by the region's federal representatives, in 2020 Congress reinstated funding to support the ecosystem and economics of the Northern Forest though NSRC. The allocation of $1.6 million over a five-year period will be used for applied forest research related to key concerns and issues of pressing importance to the forests and people of the region.

NSRC 2.0 will engage in a stakeholder-driven grant-making process. An External Advisory Committee, composed of 16 members representative of the communities, businesses, industries, and agencies in the Northern Forest region, will meet annually to advise the NSRC Executive Committee (i.e., state directors, HBRF director, and USDA Forest Service representative) about specific research needs for the request for proposals (RFP). Initially, the research framework will fall into three categories: state of the forest, measuring and quantifying impacts, and developing tools for response. The first RFP under NSRC 2.0 will be released in September 2020 (visit the website for more information).

The research summaries that follow cover ongoing NSRC research projects. To learn more about NSRC and its current support of Northern Forest research, and to access project progress and final reports, visit **https://nsrcforest.org**.

Nitrogen controls on detrital organic matter dynamics in the Northern Forest: Evidence from a 26-year nitrogen addition experiment at the Bear Brook Watershed in Maine

Year 3 of 3

IVAN J. FERNANDEZ (PI), MARIE-CÉCILE GRUSELLE, SHAWN FRAVER, CHRISTIAN KUEHNE, CHERYL J. SPENCER

The main goal of this project is to better understand the influence of elevated N input on downed wood debris dynamics. Since 1989, the Bear Brook Watershed in Maine (BBWM) is a manipulative whole-ecosystem and paired-watershed experiment with one watershed receiving N fertilizer and another one remaining untreated. Prior ^{15}N tracer additions at the site allow us to determine the fate of N in decomposing wood stakes and woody debris. In this FY, staff compiled the ^{15}N isotope data of the downed coarse and fine woody debris (CWD and FWD, respectively) from both watersheds and outside the tracer application area. The latter isotope values establish the baseline on which ^{15}N enrichment in CWD and FWD are being calculated and compared between watersheds differing in N status. The standard wood 'decay stake' experiment continues at the BBWM. This study offers detailed insights into N and ^{15}N dynamics in coarse and fine woody debris concomitantly for major tree species (*Fagus grandifolia*, *Acer saccharum* and *Picea rubens*) in the Northern Forest in relation to ecosystem N status.

Objectives

- Determine the biomass, C and N concentrations, and ^{15}N composition, of downed woody detritus in the treated and the reference watersheds at the BBWM by species and decay class.
- Compare C and N dynamics and ^{15}N recoveries in standard 'decay stakes' of *Acer saccharum* and *Picea rubens* between watersheds in a field decomposition experiment.
- Test the influence of ecosystem N status, decay stake characteristics (tree species, initial wood density and chemistry), and local drivers of decomposition on C and N dynamics and ^{15}N recoveries of *Acer saccharum* and *Picea rubens* wood 'decay stakes' in a field decomposition experiment.

Approach

This study combines a descriptive and an experimental approach and capitalizes on the well-established infrastructure and existing long-term ecosystem data from the BBWM.

In the ***descriptive approach***, CWD, FWD were sampled in both watersheds as well as outside of the reference East Bear Watershed between June and October 2017 for chemical analysis (C, N, ^{15}N). Sampling of downed coarse and fine dead wood pieces outside the BBWM but in the research area was performed to accurately estimate the 15N recovery in decomposing fine and coarse woody debris. At the time of sampling, species identity, decay class, and dimension of CWD and FWD were determined. The chemical analysis for C, N and ^{15}N coupled with biomass data will allow us to calculate C, N and ^{15}N recoveries in CWD and FWD components that ultimately will be compared between watersheds (i.e. ecosystem N status). The effects of species identity and decay class on C, N and ^{15}N recoveries in CWD and FWD components will also be tested.

In the ***experimental approach***, the field decomposition experiment using standard *Acer saccharum* and *Picea rubens* wood 'decay stakes' continued. We now have four years of decomposition since the installation of the stakes in July 2016. The decay-stake method allows us to follow wood decomposition and the fate of N in decomposing wood materials in the field by making use of pre-existing whole watershed ^{15}N pulse-chase labeling experiments at the BBWM. It will also enable us to compare the wood decay rate and ^{15}N recoveries between *Acer saccharum* and *Picea rubens* at the same site. Lastly, this experiment will allow us to test whether the shorter the distance between the decay stakes and the decaying log of the same species, as the source of the decaying fungi, enhances the decomposition of the decay stakes (see proposal for the stakes installation scheme).

Key Findings

- CWD and FWD were sampled and characterized on site by species, decay class, and dimension in summer 2017, dried, weighed and processed in the laboratory at the University of Maine (2017-2019), and analyzed for C, N and ^{15}N at the UC Davis Stable Isotope Facility (2018-2019).
- Across species, decay class, and size class, a total of 35 CWD and 43 FWD were sampled outside the two watersheds to measure their ^{15}N natural abundance. This step was necessary because of the prior ^{15}N tracer additions in the N-elevated watershed (1990-92 and 2012) and the reference watershed (2012). ^{15}N natural abundances of woody debris across species and decay classes were in the

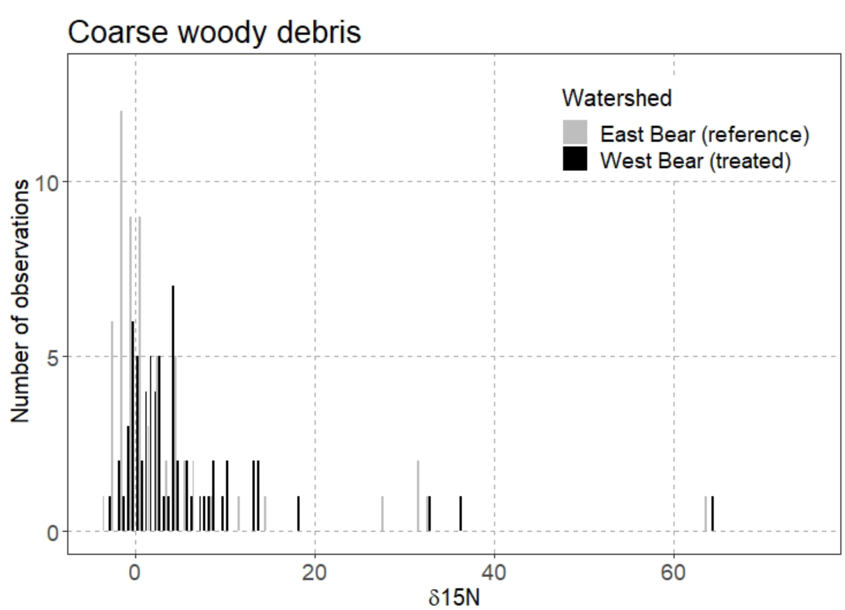


Figure 17. **Frequency distribution of $\delta^{15}N$ values of CWD by watershed.** Note: Two CWD samples from the reference watershed exhibited values of 96.23‰and 153.93 ‰and were omitted for the sake of readability

minimum–maximum range of -2.43 to 1.07‰ and -4.91 to -0.04‰ for CWD and FWD samples, respectively.

- Across species, decay class, and size class, a total of 134 CWD and 165 FWD were sampled across both watersheds. The frequency distribution of $\delta^{15}N$ values by watershed is shown in Figure 17 for CWD and Figure 18 for FWD. The measured $\delta^{15}N$ within the watersheds was well beyond the ^{15}N natural abundances measured outside the two watersheds. This shows a lasting ^{15}N enrichment in downed dead woody debris since the CWD and FWD were sampled a minimum of 5 years after the latest N tracer addition of 2012.
- A manuscript emphasizing the effects of ecosystem N status on ^{15}N recoveries in CWD and FWD at the BBWM is under development to report on the above-mentioned findings.

OUTCOMES

Accomplishments

- In forests, dead wood is an understudied ecosystem component compared to trees, leaf litter, and soil. Our study focusses on the effects of ecosystem N status on downed dead wood dynamics. Moreover, thanks to its location at the BBWM, a manipulative whole-ecosystem and paired-watershed experiment, the data gained throughout the present study provides a detailed view of the distribution of C, N, and ^{15}N in downed woody debris for three major species in the Northern Forest while leveraging knowledge and data available for C, N, and ^{15}N in all other above-mentioned ecosystem components regarding ecosystem N status.

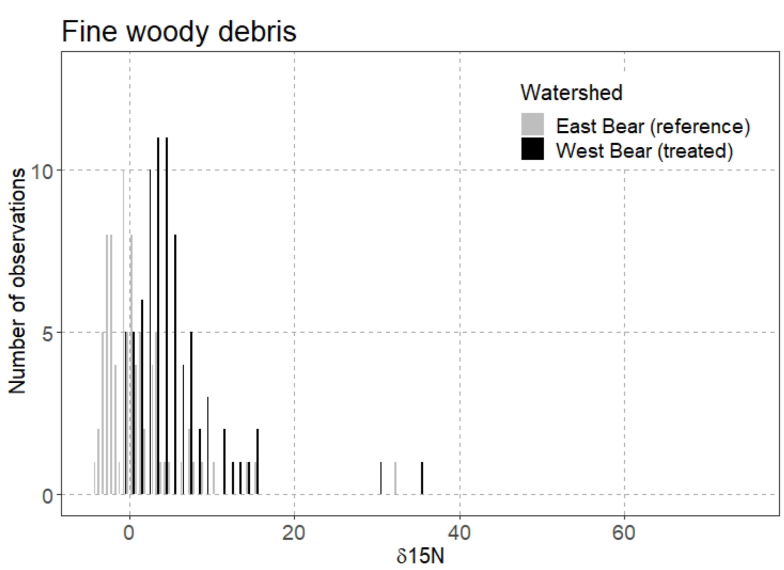


Figure 118. Frequency distribution of δ15N values of FWD by watershed. Note: One FWD sample from the reference watershed and one from the treated watershed exhibited values of 99.80 ‰ and 162.80 ‰, respectively, and were omitted for the sake of readability.

- Regarding objective 1 of the present study, all C, N, and ^{15}N analyses of CWD and FWD are completed. Data were checked and compiled in summer 2019 by Cheryl J. Spencer.

Significant Challenges

- Dr. Gruselle is in charge of C, N, and ^{15}N data analysis and manuscript writing. As noted in our previous report, the manuscript aims at quantifying C and N budgets at the BBWM including downed

CWD and FWD C, N content and isotopic recoveries and comparing these parameters between the N-elevated and the reference watersheds.

- The main challenge in this project in FY 2020 is related to manuscript writing. Indeed, Dr. Gruselle accepted a full-time professional development curriculum from September 2019 to March 2020 in Germany. In addition, due to the COVID-19 related lock-down in Spring 2020 in Germany, Dr. Gruselle was out-of-office for child care from March 17 until June 15.
- Regarding objectives 2 and 3 of the present study, the collection of the 1st set of decay stakes at the BBWM has been postponed. This was a concerted decision among the PIs in order to increase the potential to detect environmental effects on wood decay as wood decay is notably slow.

Future Plans and Opportunities

A plan is being developed by the PIs to collect the 1st set of standard decay stakes at the BBWM and meet objectives 2 and 3 of the present study. Details will be presented in the final report in March 2021.

Stillwater sunset. Photo courtesy M. Fergusson

Understanding Landscape-level Factors Influencing Spruce Budworm Outbreak Patterns in Maine and Forecasting Future Risk

Final Progress Report

Parinaz Rahimzadeh-Bajgiran (PI), Aaron Weiskittel, Daniel Kneeshaw, David MacLean, Cen Chen

Spruce budworm (SBW; *Choristoneura fumiferana* (Clem.)) defoliation during its periodic yet extensive outbreaks greatly affects forest productivity at large spatial and temporal scales. However, currently there lacks a generalized modeling framework that simultaneously accounts for both the highly varied spatial and temporal dynamics of SBW outbreaks as long-lasting debates on SBW population dynamics across the landscape continue. In this study, a highly flexible, parametric spatio-temporal model to explicitly predict SBW defoliation in continuous space and time was developed to evaluate the dynamics of SBW outbreaks across a complex forested landscape. The development of this model was based on extensive defoliation data covering approximately 50,000 km^2 and 10 years of the last SBW outbreak during the 1970s -1980s in Maine, USA, along with observations of various environmental factors. Simulations based on our model show that defoliation generally becomes ubiquitous in three years despite varying environmental and stand conditions over large ranges. Our model also indicates that current-year defoliation has almost no relationship with defoliation more than one year ago at the same location, which implies that SBW dispersal likely plays a significant role in sustaining highly dynamic defoliation across space and time. Consequently, mitigation practices like insecticide spraying may be more efficient if applied early to initial spots (epicenters) of defoliation, while management probably should focus on improving forests' resilience to withstand repeated defoliation by altering species composition. This model is readily extendable for evaluating spatial and temporal dynamics of other forms of insect defoliation across forest landscapes.

Objectives

The main goal was to model spatial and temporal dynamics of a spruce budworm outbreak across the complex forested landscape of Maine, USA. Specific objectives were:

- To develop a parametric model flexible enough to explicitly evaluate spatial and temporal dynamics of SBW outbreak
- To identify influential factors affecting spatial and temporal dynamics of SBW defoliation across the landscape;
- To apply the developed model to simulate the development of an outbreak simultaneously over space and time under various scenarios.

Approach

Study area: The spruce-fir (*Picea-Abies*) forests in the state of Maine, USA which were primarily distributed across the northern parts of the state. The extent of the defoliation data was 44.94°-47.30° N and 67.30°-70.73° W, which covered an area of approximately 50,000 km^2 and most of the spruce-fir forests in Maine.

Data

- *Growth Impact data:* The Growth Impact Study between 1975 and 1985 collected data at 424 sample plots spread across the spruce-fir forests of Maine and covered most of the duration of the last SBW outbreak (Solomon and Brann 1992).
- *Daily summaries of temperature:* the temperature data are part of the Global Historical Climate Network data available from the National Centers for Environmental Information of the USA, of which only those observed at the 62 stations located in the State of Maine were used in this study during the years of 1975 to 1984.
- *Monthly summaries of wind:* The wind data are monthly aggregations of daily wind observations at 70.30ºW, 43.64ºN in Maine from the same source above.
- *Land cover:* The National Water-Quality Assessment Project refined the US Geological Survey historical land use and land cover data derived from aerial photographs from the 1970s having 96 m spatial resolution (Hitt 1994).
- *Digital elevation model (DEM):* A 30-meter resolution DEM of Maine from the Maine Office of GIS was used to extract elevation data in the study area. This information was used to compute differences in elevation between any two locations (ΔE, positive if the destination location is higher in elevation than the source location of defoliation, and negative otherwise) in order to show the vertical structure of the landscape and to supplement the landscape connectivity.

Method

Our simulations of spatial and temporal dynamics of an SBW outbreak across the landscape were based on predictions of percentage defoliation (an indirect measure of SBW populations) at every specific location and time. These predictions were attributed to endemic factors (i.e., intrinsic stand characteristics, e.g., species composition) and epidemic factors (e.g., landscape structure and weather conditions affecting the dispersal of SBW). These two groups of factors were additively combined into a spatially and temporally weighted regression model, in which influences of epidemic factors from neighboring locations on a specific location were weighted by their distances in space and lags in time. Obviously, endemic factors at each specific location itself were not weighted.

Table 3. Scenarios in simulations of spatial and temporal dynamics of SBW outbreaks, where *D* is stand relative density, *C* is host tree percentage, $\boldsymbol{W_v}$ is the velocity of wind, $\boldsymbol{W_d}$ is the direction of wind, *H* is dominant height, *L* is the metric of landscape connectivity, *Def* is defoliation, and *ΔE* is the difference in elevation.

Predictor	Reference	Scenario							
		a	*B*	*c*	*d*	*e*	*f*	*g*	*h*
D	0.31 (1975 mean)		as reference					0.20	0.40
C	59% (1975 mean)					50%	75%		
W_v	11.2 m s^{-1} (1975 mean)			5.0 m s^{-1}	15.0 m s^{-1}				
W_d	225° (1975 value)	270°	315°						
H	19.0 m (1975 mean)						as reference		
L	0.60 (1975 mean)								
Def	preset initial values								
Δ*E*	as is								

This model shares similarities with the one proposed by Meyer et al. (2012) in the decomposition of a transmissible event into endemic and epidemic components, as well as predicting this event in continuous space and time. Simulations of spatial and temporal dynamics of an SBW outbreak were performed at a resolution of 10 km across a demonstrative area of 160 km (longitudinal) × 240 km (latitudinal). These simulations were based on the above model and scenarios defined in Table 3.

Key Findings

Influential factors of spatial and temporal dynamics of an SBW outbreak

Parameter estimates for the predictors in our model are presented in Table 4.

- The most influential factor in SBW defoliation dynamics across the landscape is defoliation itself (at a given forest location and its neighbors). It has a 31.7 times influence compared to the least influential factor of stand relative density (as a reference, i.e., its influence was scaled to be one) when the mean distance between forest locations is 40 km.
- Landscape connectivity is the second most influential factor while host tree percentage is the most influential endemic factor (intrinsic stand characteristic) of those affecting SBW outbreak dynamics evaluated in this study.
- Increases in landscape connectivity and stand relative density, as well as decreases in elevation from source to destination locations of defoliation reduce the level of defoliation at the destination location.
- Increases in defoliation (at a forest location itself and neighboring locations), host tree percentage, wind, stand dominant height, and differences in elevation are all positively related to subsequent intensification of an SBW outbreak.

Table 4. Parameter estimates, standard errors, and p-values for the predictors in our model.

Predictor	Symbol	Unit	Parameter estimate	Standard error	p-value
interaction between relative density and dominant height	$D \cdot H$	0-1 ratio · m	-1.383	0.118	<0.01
dominant height	H	m	0.583	0.047	<0.01
interaction between relative density and host tree percentage	$D \cdot C$	0-1 ratio · %	41.73	2.575	<0.01
Defoliation	Def	%	0.093	0.003	<0.01
landscape connectivity	L	0-1 ratio	-18.59	4.356	<0.01
wind	W	m s^{-1}	1.127	0.479	0.02
interaction between wind and elevation difference	$W \cdot \Delta E$	m s^{-1} · m	0.016	0.011	0.12

Simulations of spatial and temporal dynamics of an SBW outbreak

- Host tree percentage and velocity of wind have noticeably greater effects than the other factors on the spread and intensification of SBW defoliation across the landscape in simulated outbreaks
- SBW defoliation spreads over long distances (100+ km in cases) and results in relatively distinctive spatial patterns of defoliation in the first two years of simulated outbreaks in various scenarios. However, defoliation generally becomes ubiquitous in three years despite it is initiated in at only four locations in all scenarios (Figure 19).

OUTCOMES

Accomplishments

This study is aligned with UMaine's Strategic Vision and Values framework (SVV) as it supports Maine's economy and impacts the future environment and economy of Maine. Maine is at the beginning of the next SBW outbreak, and the projected economic impact in Maine for a severe and moderate outbreak are $794 and $397 million/year, respectively, with outbreaks lasting 5-15 years.

Future Plans and Opportunities

Building on findings of this research we have been able to secure more funding and we keep working on studying SBW defoliation extent, severity and risk analysis for the current outbreak in northeast USA in particular Maine.

Figure 129. Simulated spatial and temporal dynamics of an SBW outbreak under various scenarios introduced in Table 3.

Penobscot Research Forest

The Penobscot Experimental Forest (PEF) is one of **80 experimental forests and ranges** nationwide designated by the Chief of the **U.S. Forest Service** for long-term ecology and management research. Land for the PEF was purchased in 1950 by nine pulp, paper, and land-holding companies and leased to the Northeastern Forest Experiment Station (now the **Northern Research Station**) of the U.S. Forest Service as a site for long-term forest management research in the northeastern spruce-fir forest. In 1994, the industrial owners of the PEF donated the land to the University of Maine Foundation. When the PEF was donated, the industrial owners stated that the mission of the forest is: to afford a setting for long-term research conducted cooperatively among Forest Service scientists, university researchers, and professional forest managers in Maine; to enhance forestry education of students and the public; and to demonstrate how the timber needs of society are met from a working forest. Today, the University of Maine and Northern Research Station manage the PEF under a Joint Venture Agreement.

Research

The PEF is home to **long-term silviculture and ecology research** by the Forest Service (**1950s to present**) and the University of Maine (1990s to the present), contributing to sustainable management of working forests in Maine and elsewhere. The CRSF has partnered with the Forest Service to maintain their large-scale silviculture experiments across 1,000 acres of the PEF. This work includes the Management Intensity Demonstration (1950-present), **Compartment Management Study (1952 to present)**, Biomass (Whole-Tree and Stem-Only) Harvesting Study (1964 to present), Precommercial Thinning x Fertilization Study (1976 to present), and Silvicultural Rehabilitation Study (2008 to present). Treatments are applied at the stand level and include single-tree selection cutting on 5-, 10-, 15-, and 20-year cutting cycles, modified (guiding) and fixed diameter limit cutting, uniform and irregular shelterwood, precommercial and commercial thinning, and commercial and silvicultural clearcutting. Harvesting operations have evolved over time from hand crews with horse or cable skidding to mechanized harvesting with processors, forwarders, or grapple skidding. As such, treatment application and outcomes are relevant to contemporary forest management, and **measured response variables** include a suite of commodity production and ecological variables.

In addition to collaborating on data collection, analysis, and presentation or publication of the results of PEF research, the Center has supported Forest Service research data and archive management leading to **publication of permanent sample plot data** from many studies. As a result, the PEF is a national leader in experimental forest data publication and a valuable resource for researchers worldwide interested in using longitudinal forest data in their studies. The PEF is also the location of a **Smart Forest** network installation, linking wireless sensor data collection across sites.

Education and Demonstration

In addition to a number of demonstration areas, the PEF provides opportunities for training and education of University students and others through field tours, workshops, and summer and school-year employment. Numerous graduate student and faculty research projects have been overlain on the Forest Service experiments, making the PEF a key part of both research and academics at the University.

Penobscot Experimental Forest: Sustaining Productive Forests

LAURA KENEFIC (PI), AARON WEISKITTEL

Summary

The PEF celebrated its 70-year anniversary in 2020. This marks an important milestone for one of the longest, replicated, continuously inventoried and treated forest management experiments in North America. During this year, collaboration between the U.S. Forest Service and Center for Research on Sustainable Forests continued its longstanding partnership to generate and communicate findings from existing and newly established long-term studies (Figure 20) at the PEF and companion sites on commercial and other public and private forestland. This work included collecting data and applying treatments in large-scale replicated experiments of even- and uneven-aged silviculture and exploitive cutting, as well as lowland northern white-cedar silviculture and operations. Post-harvest and post-burn data were collected in the long-term biomass harvesting study, with a focus on regeneration response and herbivory. In addition, a historical longitudinal investigation of beech bark disease was re-measured in collaboration with University of Maine students and faculty. Finally, a large project was undertaken and completed to provide sub-meter accuracy GPS data for all long-term management unit, plot, and selected tree locations for use by researchers and students.

Prior to the stay-at-home order in March, a half-dozen field tours were given to visitors from throughout eastern North America; findings from research were also presented at regional, national, and international workshops, meetings, and conferences. Eleven publications were authored by researchers at the PEF, University of Maine, and elsewhere who were working at or using data from the long-term Forest Service experiments there.

Key Findings / Accomplishments

- Remeasurements and timber marking were completed in a number of long-term silviculture studies on the PEF by University of Maine student and recent-graduate employees, with precommercial crop tree release on 50 acres. *This represents the 70th year of continuous inventory and treatment application.*

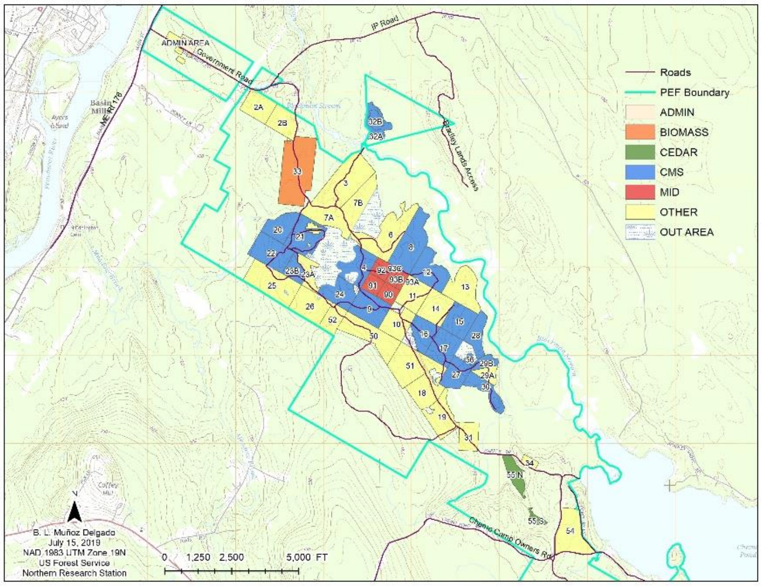


Figure 20. PEF stand plots. Courtesy USDA Forest Service.

- The 40-year-old study of beech bark disease was re-measured and preliminary findings on the emerging concept of beech bark disease were presented on field tours and by B.S. student Lauren Keefe for her senior capstone project (Advisor: William Livingston).
- The 60-year-old biomass harvesting study (*the oldest known study comparing whole-tree and stem-only harvesting in temperate forests worldwide*) was re-measured one year following harvesting and burning; data on regeneration response and browsing were presented on field tours and at conferences and by B.S. student Michaela Kuhne for her honor's thesis (Advisor: Amber Roth)
- Replicate study sites were established for the lowland northern white-cedar experiment on Wagner and Baskahegan forestland. Pre-harvest data were collected at both sites; the Baskahegan site was marked and harvested and post-harvest data collected. Replicate study sites were also established at the Dukes Experimental Forest in Michigan, with data collection planned in coming years.
- M.S. student Maren Granstrom completed and defended her thesis on the 65-year assessment of the silvicultural, economic, and ecological outcomes of the long-term Forest Service research at the PEF and produced two videos shared widely online (*more than 4,000 views to-date*).
- PI Kenefic and staff gave on-site field tours to more than 70 visitors from academic and governmental institutions including the U.S. Forest Service, State and Private Forestry; U.S. Forest Service, Pacific Northwest Research Station; University of Vermont; and University of Maine (including three class visits).
- Hosted a two-day workshop on wetland delineation for the United South and Eastern Tribes in collaboration with the University of Maine Forests Office, Maine State Soil Scientist, and U.S. Geological Survey.
- Findings from Forest Service research at the PEF were presented by PI Kenefic and staff at three off-site field tours by invitation: a northern white-cedar field tour organized by the Vermont Land Trust and Forest Guild, an in-field consultation with National Forest System staff in New Hampshire, and a mixedwood ecology and management tour in Quebec, Canada.

- Based on the body of work at the PEF and her expertise, PI Kenefic is serving by invitation of the President of the University of King's College at Dalhousie as a scientific expert in a year-long external review of implementation of ecological forestry in the Province of Nova Scotia.
- Laura Kenefic was awarded the prestigious David M. Smith Award for her silviculture research at the PEF by the New England Society of American Foresters.

Future Plans

- Complete and publish the companion landowner's guide to sustainable forest management that accompanies the Granstrom videos: a collaboration between the University of Maine, U.S. Forest Service, Maine Audubon, and New England Forestry Foundation
- Re-purpose a number of inactive management units at the PEF for new collaborative University of Maine – U.S. Forest Service studies of mixedwood (hardwood – softwood) management and climate change mitigation
- Measure post-harvest vegetation, microtopography, and impacts of operations in the northern white-cedar study on Wagner forestland
- Further develop and disseminate findings from the beech bark disease tolerance study
- Generate new management guidelines for practitioners and science delivery products for students and the public on the topics of silviculture, mixedwood management, biomass harvesting, and forest health.

Plot signposts on the PEF. Photo courtesy M.Fergusson.

Howland Research Forest

Home to the second-longest flux record in the United States (20+ years, since 1996), the Howland Research Forest is a founding member site of the Ameriflux network. The site maintains three eddy flux towers; two towers (the "main" and "west" towers) are located in a mature spruce–hemlock forest approximately 800 meters apart. Howland has the second longest running flux record in the United States, dating back to 1996 (the longest belonging to Harvard Forest). These decades of data provide a time series long enough for robust analyses of relationships between CO_2 flux and various environmental variables.

Established in 1986 through a partnership between the University of Maine and International Paper Company, Howland Research Forest's forest ecosystem research site located in central Maine has hosted numerous collaborations between the **USDA Forest Service, NASA, NOAA, EPA,** the **US Department of Energy, Woods Hole Research Center**, and the **University of Maine**. The CRSF continues to support an active research program in Howland focused on carbon and nutrient cycling, remote sensing, climate change, and more.

Ameriflux Research at the Howland Forest

Shawn Fraver (PI), Dave Hollinger, John Lee, Holly Hughes

Summary

The AmeriFlux network is a nationwide set of research sites measuring fluxes of CO_2, water, energy, as well as other terrestrial processes, to quantify the forest carbon cycle and the response of terrestrial ecosystems to climate and disturbance. The Howland Research Forest, Maine, is one of the Core Sites of the AmeriFlux program. The general expectations for Core Sites include providing high quality continuous data with long-term duration, participating cooperatively in the network, and being responsive to Department of Energy requests.

Project Objectives

The primary objective of this project is to support ongoing research activities at the Howland Research Forest, Maine. These activities include:

1. Providing overall technical support for the CO_2 flux, meteorological, soil flux, and ecological activities associated with the Howland Forest AmeriFlux site

2. Assisting with sensor calibration, telecommunications, flux calculations, data processing, and ecological measurements
3. Ensuring adequate communication between the University of Maine and Forest Service personnel regarding project status
4. Sharing data freely with the AmeriFlux Management Project, and various AmeriFlux data repositories
5. Providing general upkeep and safety of the Howland Forest site, including liaising with the Howland Forest landowner

Approach

The project objectives are met through the work of two full-time Research Associates, John Lee and Holly Hughes. In addition, the infrastructure and continuous, long-term data at Howland Forest provide an ideal framework for graduate student research, which is conducted through the School of Forest Resources. Such research allows us to address additional questions complementary to the core Ameriflux mission, thereby expanding the project's reach and scope.

Co-Principal Investigator Dave Hollinger inspects recent blowdown at the Howland Research forest, Maine. Photo courtesy Shawn Fraver.

Key Findings / Accomplishments

The Howland Forest site has had continuous atmosphere-forest canopy CO_2 flux data since 1996, making it the second longest running canopy flux site in North America.

Partners / Stakeholders

Andrew Richardson, Northern Arizona University, Flagstaff, AZ; Kathleen Savage, Woods Hole Research Center, MA; Jennifer Watts, Woods Hole Research Center, MA; Aaron Teets, Northern Arizona University, Flagstaff, AZ; Amanda Armstrong, NASA Goddard Space Flight Center, MD; Jamis Bruening, University of Maryland, MD; Northeast Wilderness Trust, Montpelier, VT.

Holt Research Forest

The Holt Research Forest (HRF)'s 300-acre site has been the site of a long-term pine-oak forest ecosystem study continuously since 1983, collecting data on trees and regeneration, small mammals, and a variety of avian species. Since its inception, HRF has been a site for cooperating researchers, training opportunities for graduate and undergraduate students, and public service and outreach to the community. The HRF research plan has two goals: (1) to monitor long-term changes in animal and plant populations and (2) to document the effects of forest management on these species. The HRF is supported by the CRSF, with the majority of its funding coming from the Maine TREE Foundation.

Continuous, long-term data sets in ecology such as the one at HRF are rare and unusually valuable. Most ecological research operates in time scales of 2-5 years, driven by cycles of funding and graduate projects, while ecological processes often occur over decades. The HRF is the only operating oak-pine research forest in Maine and it is one of only two forests (with the Harvard Forest) dedicated to oak-pine research in the Northeast. Though the oak and pine forest types represent only 10% of Maine's forestland, over 80% of the forest cover in Maine's southern counties is oak pine types and it is responsible for a significant portion of Maine's total forest economy. To learn more about the Holt Forest, visit **holtforest.org**.

Holt Research Forest

JACK W. WITHAM (PI), AARON WEISKITTEL, CLARKE T. COOPER

Summary

Progress continued on many fronts at Holt Research Forest (HRF). Overall goals continue to be long-term monitoring of forest conditions but with a new emphasis on documenting changes from a Maine TREE Foundation conducted harvest in 2020. No tree harvesting has taken place since 1988 so this will provide HRF with an opportunity to develop new research to monitor the impacts on the forest ecosystem. Major goals will be to document the changes in forest structure and its impact on the forest components. How to successfully regenerate red oak will be a high priority for research outcomes.

Data collection in anticipation of this harvest has been a major focus. In 2019, we began re-measuring trees and tree regeneration plots and this process continued to the 2020 field season. In 2020, we began a survey to measure plant species distribution and abundance with relevé surveys in 120 subquadrat (25x25m) plots. Many of our yearly monitoring projects were completed. Game cameras recorded images

Table 5. Small Mammal Captures 2019 at Holt Research Forest.

Species	Total Captures	# of Individuals
Masked Shrew (*Sorex cinerius*)	2	2
Short-tailed Shrew (*Blarina brevicauda*)	3	3
Eastern Chipmunk (*Tamias striatus*)	2	1
Red Squirrel (*Tamiasciuris hudsonicus*)	2	1
Southern Flying Squirrel (*Glaucomys volans*)	1	1
White-footed Mouse (*Peromyscus leucopus*)	19	7
Red-backed Vole (*Clethrionomys gapperi*)	5	2
Meadow Jumping Mouse (*Zapus hudsonicus*)*	1	1
TOTAL	35**	18**

at HRF to provide our first definitive look at mammalian predators since winter track counts in the 90's. These species can have a profound influence on small mammal populations. Twelve mammal species were recorded visiting the baited locations (Table 5).

Objectives

- Long-term monitoring of forest ecosystem
- Complete data management project with all data sets publicly posted and data sheets scanned
- Complete GIS input of bird mapping data
- Host educational programs for forest landowners and natural resource professionals
- Implement HRF Strategic Plan
- Preparation for 2020 timber harvest

Approach

- Work with collaborators to develop research and management plan
- Data sharing most data now available at FEMC website
- Collection of key data sets and hire student workers to collect additional data
- Work with Maine TREE Foundation to design harvest strategy

Key Findings

- Completed data acquisition for 37th field season and began 38th

Undergraduate timber inventory crew members Danielle Wyman, Meredith Melandy, and Henry Amponsah (L to R) pause from their work for a photo. Photo courtesy Jack Witham

- Data management process completed on 90% of data sets
- Hosted one land owner workshop at HRF
- HRF videos available on website and submitted to MPBN for broadcast

OUTCOMES

Accomplishments

- Providing authentic experience in research to 8 students including 7 undergraduates and an MF student from Ghana.
- Collaboration with Maine Medical Center Insect Borne Disease Lab to better understand the small mammal/black-legged tick/disease mechanism
- Collaboration with US Forest Service to conduct parallel harvests and studies with Massabesic Experimental Forest
- Surveyed for mesopredators with 20 game cameras for 3 months. Documented twelve mammal species including fisher.
- Completed re-measurement of trees (complete inventory on 9 ha) and 200m^2 (n=73) and 4m^2 (n=292) regeneration plots.
- Completed gridline maintenance on approximately 13 km of trail. This included painting quadrat lines (nearly 8 km) and subquad lines (nearly 6 km)
- Completed most of the usual yearly monitoring projects
- Completed input of bird territory mapping data
- New interpretive signs installed.
- All (1983-2018) data sheets scanned.
- Awarded a Maine Outdoor Heritage Fund grant to employ 2 students.

Significant Challenges

- Insufficient funding to meet the research needs, especially for personnel.
- Replacement and engagement with a partner at Maine Forest Service for educational activities.

- Research activity somewhat constrained by limitations of Covid19.
- Hosting outdoor educational events/tours/activities limited due to Covid19.

Future Plans and Opportunities

- Reestablish grid system, other plots, seed traps
- Monitoring changes in forest ecosystem due to harvest
- Post-harvest timber inventory and other measurements
- Mapping harvest gaps
- Fund, purchase, and set up deer exclosures
- Establish location of prescribed burning
- Seek funding for instrumentation at HRF
- Education programming demonstrating sustainable forest management

Partners / Stakeholders

US Forest Service, Maine Forest Service, Maine TREE

Holt student field crew members Jasmine Gregory, Emily Roth, and Nathaniel Harris (L to R) show off a recently installed interpretive sign. Photo courtesy Jack Witham.

Research Products and Outputs

Refereed Journal Publications (14)

Bhattarai, R., Rahimzadeh-Bajgiran, P., Weiskittel, A., and MacLean, D. 2020. Sentinel-2 based prediction of spruce budworm defoliation using red-edge spectral vegetation indices. Remote Sensing Letters 11: 777-786.

Boone, S.R. & A. Mortelliti. 2019. Small mammal tree seed selection in mixed forests of the eastern united states. Forest Ecology and Management, 449, 117487. doi:10.1016/j.foreco.2019.117487

Brehm, A.M., A. Mortelliti, G.A. Maynard, & J. Zydlewski, J., 2019. Land-use change and the ecological consequences of personality in small mammals: Ecological consequences of personality. Ecology Letters, doi:10.1111/ele.13324

Evans, B.E., C.E. Mosby, & A. Mortelliti. 2019. Assessing arrays of multiple trail cameras to detect North American mammals. PLoS ONE 14(6): e0217543

Fien, E.K.P., S. Fraver, A. Teets, A.R. Weiskittel, & D.Y. Hollinger. 2019. Drivers of individual tree growth and mortality in an uneven-aged, mixed-species conifer forest. Forest Ecology and Management 449: 117446.

Hastings, J.H, Ollinger, S.V., Ouimette, A.P., Sanders-DeMott, R.W., Palace, M.J., Ducey, M.B., Sullivan, F.A., Basler, D., & Orwig, D. 2020. Tree species traits determine the success of LiDAR-based crown mapping in a mixed temperate forest. Remote Sensing, 12(2):309. doi: 10.3390/rs12020309

Kuehne, C., Russell, M. B., Weiskittel, A. R., & Kershaw, J. A. 2020. Comparing strategies for representing individual-tree secondary growth in mixed-species stands in the Acadian forest region. Forest Ecology and Management, 459, 117823.

Legaard, K., E. Simons-Legaard, & A. Weiskittel. 2020. Multi-objective support vector regression reduces systematic error in moderate resolution maps of tree species abundance. Remote Sens 12: 1739. doi 10.3390/rs12111739

Ouimette, A.P., Ollinger, S.V., Lepine, L.C., Stephens, R.B., Rowe, R.J., Vadeboncoeur, M.A., Tumber-Davila, S.J., & Hobbie, E.A. 2019. Accounting for carbon flux to mycorrhizal fungi may resolve discrepancies in forest carbon budgets. Ecosystems, 1-15. doi: 10.1007/s10021-019-00440-3

Puhlick, J. J., S. Fraver, I.J. Fernandez, A. Teets, A.R. Weiskittel, & L.S. Kenefic. 2019. Site quality, disturbance, and vegetation effects on carbon storage and accumulation in old, mixed-species stands in central Maine, USA. Natural Areas Journal, 39(4), 429.

Rahimzadeh-Bajgiran, P., Hennigar, C., Weiskittel, A., and Lamb, S. 2020. Forest potential productivity mapping by linking remote-sensing derived metrics to site variables. Remote Sensing 12: 2056.

Sanders-DeMott, R., Ouimette, A.P., Lepine, L.C., Fogarty, S.Z., Burakowski, E.A., Contosta, A.R., & Ollinger, S.V. 2020. Divergent carbon cycle response of forest and grass-dominated northern temperate ecosystems to record winter warming. Global Change Biology, 26(3)1519-1531. doi: 10.1111/gcb.14850

Soman, H., A.R. Kizha, B. Muñoz Delgado, L.S. Kenefic, & K. Kanoti. 2020. Production economics: Comparing hybrid tree-length with whole-tree harvesting methods. Forestry: An International Journal of Forest Research

Weiskittel, A. R., & Kuehne, C. 2019. Evaluating and modeling variation in site-level maximum carrying capacity of mixed-species forest stands in the Acadian region of northeastern North America. The Forestry Chronicle, 95(3), 171-182.

Research Reports (6)

Affleck, D. and Weiskittel, A. 2020. Alternative modeling strategies for estimating tree biomass across a nationwide system of inventory plots. In: Brandeis, T.J., comp. Celebrating progress, possibilities, and partnerships: Proceedings of the 2019 Forest Inventory and Analysis (FIA) Science Stakeholder Meeting; November 19-21, 2019; Knoxville, TN. e-Gen. Tech. Rep. SRS-256. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 267 p.

Daigneault et al. 2020. Maine Forestry and Agriculture Climate Change Mitigation Potential. CRSF Draft Report, April 1, 2020.

Puhlick, J.J., A.R. Weiskittel, B.E. Roth, & A.S. Nelson. 2019. Evaluation of silvicultural options for increasing productivity of early successional stands in the Acadian Forest Region. Center for Advanced Forestry Systems final report.

Roth, E.E., J.J. Puhlick, & I.J. Fernandez. 2020. Relative risk of soil nutrient depletions among different intensities of tree biomass removal during timber harvesting in Maine, USA. Final Report for the Center for Undergraduate Research.

Weiskittel, A. and Radtke, P. 2020 National Scale Biomass Estimator (NSBE) Project: Next steps, implications, and future timeline. In: Brandeis, T.J., comp. Celebrating progress, possibilities, and partnerships: Proceedings of the 2019 Forest Inventory and Analysis (FIA) Science Stakeholder Meeting; November 19-21, 2019; Knoxville, TN. e-Gen. Tech. Rep. SRS-256. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 267 p.

Witham, J. 2019-2020. Quarterly progress reports on the Holt Research Forest to Maine TREE Foundation.

Data Tools and Publications (2)

Intelligent GeoSolutions Team, 2020. [Maine Forest Ecosystem Status and Trends]() (ForEST) App

Kenefic, L.F., B.L. Muñoz Delgado, N.S. Rogers, & A.P. Richley. 2020. Penobscot Experimental Forest boundary, roads, trails, management units, and permanent sample plot locations. 2nd Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2014-0008-2

Presentations / Workshops / Meetings / Field Tours (45+)

Allogio, J., S. Fraver, & L. Kenefic. 2019. Requirements for successful regeneration of northern white-cedar in lowland sites in Maine. Presented at the Northern White-Cedar: Linking Research and Management Meeting. 24 Apr. Quebec, QC.

Archambault, G., B. E. Evans, & A. Mortelliti. 2019. Developing a Novel Approach to Estimate Reproductive Success of Black Bears in Maine. POSTER. University of Maine Center for Undergraduate Research Spring Symposium. Bangor, Maine, April 10, 2019.

Barusco, B., A. Grigaitė, C.T. (Tat) Smith, I. Stupak, A. Weiskittel, A. Rezai Stevens, B.E. Roth, C. Preece, I. Fernandez, J. Zukswert, J.L. Campbell, J.Metsaranta, R.D. Briggs, S. Fraver, S. Kull, & W. Kurz. 2019. Forest carbon pool development over 35 years in a balsam fir-red spruce forest in northern Maine after stem-only and whole-tree harvesting. Poster presented at the 2019 Annual Meeting, Amer. Soc. of Agronomy, San Antonio, Texas, 11-13 November 2019.

Byerssmall, E., Millay, L., Peterson, F., McKay, S.R., Pandiscio, E., Rockwell, H., Stetzer, M., Zoellick, B. 2019. Recruiting, Preparing, and Retaining STEM Teachers in Rural, High-Need Schools: Developing a Model of Support for New Teachers Through an NSF Fellowship Program. Poster presented at the Northeast Association for Science Teacher Education Annual Conference in Burlington, Vermont, October 10-12.

Carter, J., K. Legaard, & A. Guay. Mapping Maine's land cover – a new approach. Maine Library of Geographic Information Board Meeting, Hallowell, Maine. February 19, 2020.

Chen, C., P. Rahimzadeh-Bajgiran, & A. Weiskittel. 2020. Modeling spatial and temporal dynamics of a spruce budworm outbreak across the complex forested landscape of Maine, USA, under revision.

D'Amato, A. 2020. New England adaptive silviculture for climate change: Dartmouth's Second College Grant. Society for the Protection of New Hampshire's Forests Meeting, March.

D'Amato, A. 2020. Co-designing forestry studies to address adaptation science needs. Forest Ecosystem Monitoring Cooperative Annual Meeting, March.

D'Amato, A. 2020. Silviculture of northern forests through the adaptation lens. Planning and Practices for Water Supply Reservoir Forests in the Mid-Atlantic, February.

Daigneault, A. 2020. Forest Ecosystems, Forestry, and Biodiversity. Presented at Maine Climate Council Quarterly Meeting. Augusta. January 29.

Daigneault, A. 2020. Maine Agriculture's Climate Change Mitigation Potential. Presented at Maine Climate Council Natural and Working Lands Work Group Meeting. Augusta. February 14.

Daigneault, A. 2020. Mitigation Potential of Maine's Soil Health Practices. Presented at Maine Farmland Trust Healthy Farm Healthy Soils Workshop. Presque Isle. February 19.

Daigneault, A. 2020. Putting a price on Maine's Natural Climate Solutions Part 1: Agriculture. Webinar hosted by Maine Climate Table. May 12.

Daigneault, A. 2020. Putting a price tag on Maine's Natural Climate Solutions Part 2: Forestry. Webinar hosted by Maine Climate Table. June 29.

Evans, B. E. 2019. Camera trapping as a tool for large-scale monitoring of carnivores in Maine. PRESENTATION. CFRU Fall Field Tour. Rangeley area, Maine, September 19.

Foster, J. 2019. Unexpected expansion of montane tree species under climate change: The puzzling case of red spruce in the eastern US. Departmental Seminar, Department of Biology Bryn Mawr College, November.

Foster, J. 2019. Monitoring trends in forest composition and productivity from space, field data, landscape models. Adaptive Silviculture for Climate Change Annual Meeting, December.

Foster, J. 2020. Unexpected expansion of montane tree species under climate change: The puzzling case of red spruce in the eastern US. Departmental Seminar, School of Environmental and Biological Sciences Rutgers University, March.

George A.K., & A.R. Kizha. 2019. Quantifying soil disturbance in a whole-tree operation method. Session: environmental impacts of forest operations. Session: Environmental impacts of forest operations. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), 6-9 October, Sopron, Hungary. http://formec2019.com/down/FORMEC2019_PROCEEDINGS.pdf

George, A.K., A.R. Kizha, & L. Kenefic. 2019. Northern white-cedar harvesting cost and productivity. Presented at the Northern White-Cedar: Linking Research and Management Meeting. 24 Apr. Quebec, QC. INVITED

George, A.K., A.R. Kizha, & L. Kenefic. 2019. Economic feasibility of timber harvesting in lowlands. In I. Czupy, ed. Exceeding the vision: Forest mechanisation of the future. Proceedings of the 52nd International Symposium on Forestry Mechanization. Sopron, Hungary: University of Sopron Press: 379-393.

Hahmann, T. 2020. Integration of Symbolic and Statistical AI for Environmental Informatics. iLunch Seminar Series, February.

Kizha A.R., E. Nahor, N. Coogen, L.T. Louis, & A.K. George. 2019. Residual stand damage under different silvicultural prescriptions. Session: Environmental impacts of forest operations. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), 6-9 October, Sopron, Hungary. http://formec2019.com/down/FORMEC2019_PROCEEDINGS.pdf

Kizha, A.R. 2019. Cost of timber harvesting operations and BMP execution. Prentiss and Carlisle Forest Resource Management Timberland Services. July 23, Bangor, ME.

Legaard, K., A. Guay, & J. Carter. 2020. Mapping Maine's forest and land cover: Proposed partnership between UMaine and NOAA C-CAP. Cooperative Forestry Research Unit Advisory Committee Meeting, May 6, Orono.

Legaard, K., E. Simons-Legaard, & A. Weiskittel. 2019. Review of the UMaine Intelligent Geosolutions Initiative approach to land cover mapping and landscape change detection. Mapping Maine's Land Cover, Stakeholder Engagement Workshop. Orono, Maine, August 14.

Legaard, K., E. Simons-Legaard, A. Weiskittel, & T. Hahmann. 2019. The Maine Forest Ecosystem Status and Trends (ForEST) App: Data and tools to support landscape planning and forest risk analysis in real time. USFS 2019 FIA Stakeholder Science Meeting. Knoxville, TN, November 19.

Legaard, K., E. Simons-Legaard, A. Weiskittel, L. Whitsel, & C. Wilson. 2019. Use of multi-objective machine learning and high performance computing to reduce prediction bias in forest maps. USFS 2019 FIA Stakeholder Science Meeting. Knoxville, TN, November 20.

Millay, L., McKay, S.R., Peterson, F., Lindsay, S., Nickerson, L., Toolin, R. 2020. Connecting Middle and High School Teachers with Big Data and Quantitative Reasoning in the Context of New England Forests. Poster presented at the Maine Environmental Education Association (MEEA) Annual Conference and Research Symposium in Belfast, Maine, March 5-6.

Millay, L. 2020. Invited panelist for the UMaine Arctic Broader Impacts Seminar organized by University of Maine's Office of Research Development and UMaine Arctic at University of Maine in Orono, February 28.

Ollinger, S. 2020. Understanding the role of forests in the Earth's climate system. Climate and forest management workshop, Society for the Protection of New Hampshire Forests, February.

Ouimette, A. 2019. Does Diversity in Species Specific Leaf Traits and Resource Use Promote Stability of Forest Ecosystem Carbon and Water Fluxes? AGU Fall Meeting, December. Poster.

PEF Field tours: Eight field tours were given at the PEF for visitors from the U.S. Forest Service, State and Private Forestry; U.S. Forest Service, Pacific Northwest Research Station; University of Vermont; and University of Maine. Additional scheduled field tours were cancelled due to the covid-19 pandemic.

PEF Workshops and Meetings: Presentations were given at regional, national, and international venues including the Northern White-Cedar Workshop in Vermont, the National Experimental Forest and Range Meeting in Colorado, and the Mixedwood Ecology and Management Meeting in Quebec. Numerous accepted presentations at regional, national, and international conferences, including the New England Society of American Foresters Annual Meeting in Massachusetts, IUFRO Mixed Species Conference in Sweden, RE3 Restoration Conference in Quebec, Northern White-Cedar Workshop in Quebec, U.S. Forest Service Silvics Workshop in Illinois, and Northern Hardwood Conference in Minnesota were cancelled due to the covid-19 pandemic.

Puhlick, J. J. 2020. Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests. Sustainable Forestry Initiative Inc. Sounding Board (oral presentation), Online Workshop, May 20.

Rahimzadeh-Bajgiran P., C. Hennigar, & A. Weiskittel. 2019. Developing a refined forest site productivity map for northeastern forest of Maine and New Brunswick by linking environmental to remotely sensed variables. Joint meeting of the 21st William T. Pecora Memorial Remote Sensing Symposium (Pecora 21)and the 38th International Symposium on Remote Sensing of Environment (ISRSE38), Baltimore, MD, October 6-11.

Roth, A.M., K.W. Wilson, & L. Douglas. 2019. Woods, Wildlife, and Wind Power, CFRU Fall Field Tour, September 19, Weyerhaeuser Timberlands.

Roy, S. 2020. Partnerships for resilient river infrastructure and ecology: watershed coordination of dam and culvert management decisions in Maine Maine Sustainability and Water Conference, March.

Roy, S. 2020. Learning from dams: a multi-university case study on training the next generation of sustainability researchers. Maine Sustainability and Water Conference, March.

Sanders-Demott, R. 2019. Asynchronous Responses of Carbon Uptake and Carbon Loss to Antecedent Winter Conditions in Northern Temperate Ecosystems. American Geophysical Union Fall Meeting, December.

Simons-Legaard, E. 2020. Projecting Maine's Future Forest. Wabanaki Summit, Universisty of Maine, February.

Simons-Legaard, E. 2020. Climate and Maine's Changing Forest. Forest Climate Change and Adaptation Forum, University of Maine, February.

Simons-Legaard, E., K. Legaard, & A. Weiskittel. 2019. UMaine Intelligent GeoSolutions Initiative. Maine Department of Agriculture, Conservation, and Forestry. Augusta, ME, July 23.

Turso, M., K.W. Wilson, & A.M. Roth. 2019. Invited oral presentation to the International Bicknell's Thrush Conservation Group, Quebec City, Quebec, August 27.

Wilson, K.W. & A.M. Roth. 2019. Bicknell's Thrush Habitat Use on Commercial Forests in Maine, Invited oral presentation to the Society of Canadian Ornithologists, August 28, Quebec City, Quebec.

Witham, J. 2019. Hosted Kennebec Estuary Land Trust's summer day camp for two weeks in 2019.

Woodall, C., L. Kenefic, B. Muñoz Delgado, & C. Kern. 2019. Status and Trends of Northern White-Cedar in the U.S. Poster presented at New England Society of American Foresters Meeting. Burlington, VT, March 27-28.

Media / Web Pages / Videos (14)

"On Wilderness: Rethinking Climate Crisis" (essay by David Crews). *The Hopper*, October 2019.

Barker, C. What's the attraction? Featured in UMaine Today Fall/Winter 2019 and online feature: https://umainetoday.umaine.edu/stories/2019/whats-the-attraction/

Forestry for the Future: Lessons in Sustainable Management from Maine: https://www.youtube.com/watch?v=eykwZkKrYKg&t=4s

INSPIRES webpage, New England Sustainable Consortium website. https://www.newenglandsustainabilityconsortium.org/inspires-smart-data-resilient-forests

Maine Audubon website: https://www.maineaudubon.org/projects/forestry-for-maine-birds/

Maine Forest Service Newsletter: https://content.govdelivery.com/bulletins/gd/MEDACF-289f48c

Maine Organic Farmers and Gardeners Association Low Impact Forestry newsletter: https://www.mofga.org/Programs/Low-Impact-Forestry/MOFGA-Low-Impact-Forestry-Newsletter/forestry-for-the-future-lessons-in-sustainable-management-from-maine

Penobscot Experimental Forest Research Highlights: https://www.youtube.com/watch?v=4nB-nfguSNY&t=6s

Portland Press Herald. Maine on target to meet near-term greenhouse gas emissions goals. January 29, 2020.

The University of Maine. 2019. Elevated concerns. Available online at https://www.youtube.com/watch?v=j7ay1YYtPao

UMaine News. Daigneault looks for prosperity though the trees. April 1, 2020.

UMaine News. Daigneault to put forests, farms to work reducing greenhouse gases. March 12, 2020.

UMaine press release: https://umaine.edu/news/blog/2020/04/29/granstroms-video-showcases-long-lasting-effects-of-forestry-decisions/

Witham, J. Holt Research Forest: 3+ Decades of Ecosystem Research. Video (4 mins highlight video available on CRSF YouTube channel). Full-length video may be released by Maine Public in late 2020.

Theses (8)

Barusco, B., Grigaite, A. 2019. Forest carbon pool development over 35 years in a balsam fir -red spruce forest in northern central Maine after stem-only and whole-tree harvesting. Master of Science in Forest and Nature Management thesis, University of Copenhagen, edited version, 30 October 2019, 128 pp + appendices.

Buyaskas, M. 2019. Assessing the Effectiveness of Attractants to Increase Detection Probabilities of Northeastern Mammals. BS Honors thesis, University of Maine, Orono. 38p.

Coogen, Noah. 2019. Analyzing Residual Stand Damage under different Harvesting Methods in the Northern Maine Acadian Forest. BS Forestry, Honors Thesis. University of Maine, Orono.

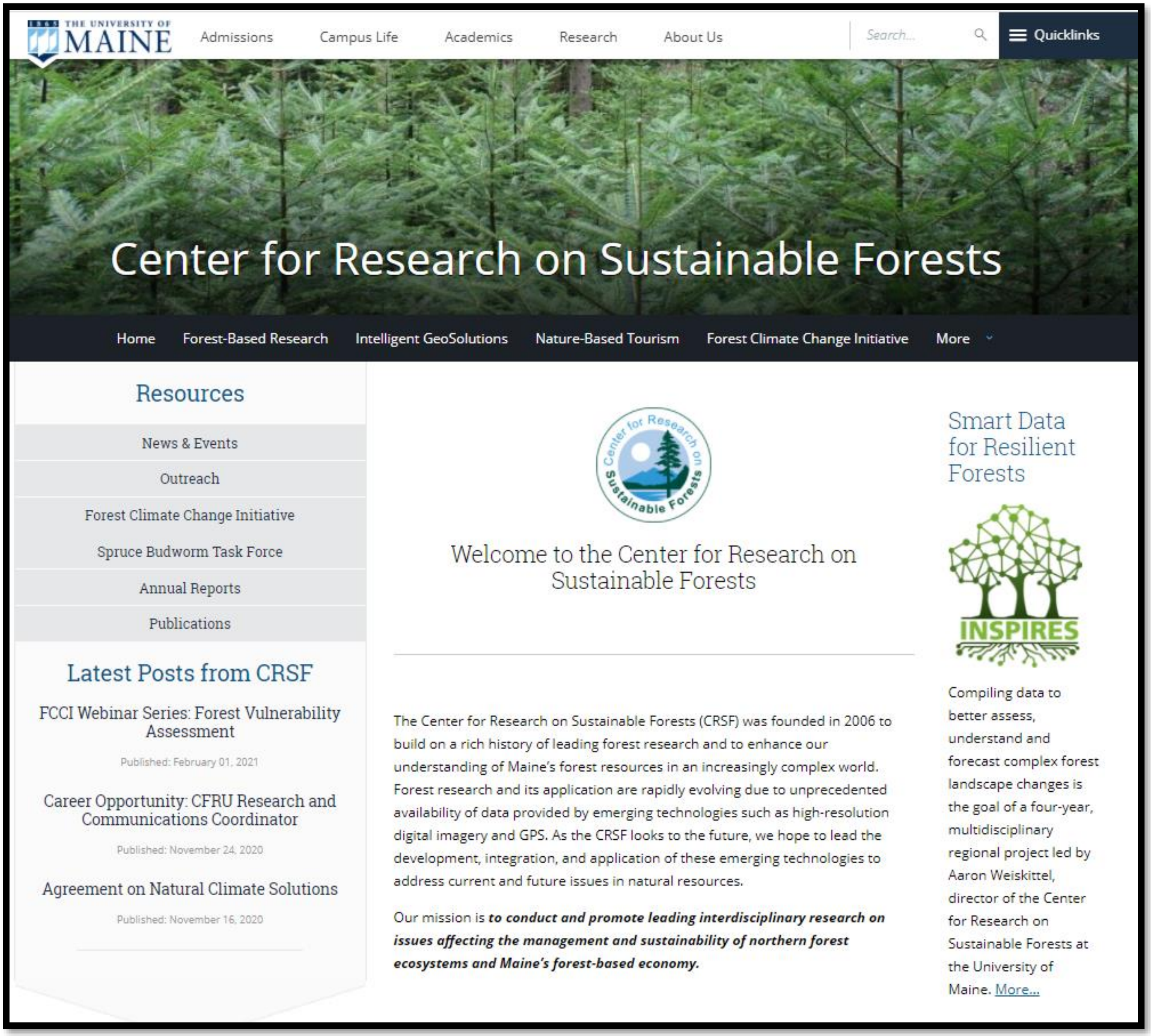
Rezai-Stevens, Adriana. 2019. Long-Term Effects of Whole-tree Harvesting and Residue Management on Spruce-Fir Soil Quality in Central Maine. Master of Forest Conservation thesis, University of Toronto. 43 p.

Soman, H. 2019. Productivity, Costs, and Best Management Practices for Major Timber Harvesting Frameworks in Maine. Master of Science in Forest Resources thesis, University of Maine, Orono.

Granstrom, Maren. 2019. Northern Conifer Forest Management: Silvicultural, Economic, and Ecological Outcomes from 65 Years of Study. Master of Science in Forest Resources, University of Maine, Orono.

Link, G. 2020. Seed dispersal effectiveness in the Penobscot Experimental Forest. BS Honors thesis, University of Maine.

Mansfield, Maggie R. 2019. Understory Response to Gap-based, Multi-aged Silviculture. Master of Science in Forest Resources thesis, University of Maine.



Learn more about the many programs and initiatives under the Center for Research on Sustainable Forests

crsf.umaine.edu

Center for Research on Sustainable Forests